A STUDY OF GROUND WATER POTENTIAL AT I. I. T. CAMPUS, KANPUR

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CERTIFICATE

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ABSTRACT

The area under investigation forms a part of the Gangetic plains in the Gangetic basin. The basin, originated as a depression during the Himalayan upheaval, has vast quantity of alluvium containing mainly clay with alternating sand and Kankar horizons of limited thickness. From 1963 till 1974 (Around April) the water supply for the I.I.T. Campus was totally from such shallow sandy aquifers which varied in their nature and extent. There were very few systematic studies on these shallow tube wells and few pumping test data and aquifer parameters were reported.

In the present study three main systems of shallow aquifers have been recognized (up to 130 m (430 ft.) depth). Pumping tests were made and ~~revealed~~ transmissibility coefficients were deduced ~~to be~~ 387500 lpd per meter (26065 gpd/ft.) and 305250 lpd per meter (20500 gpd/ft) for the aquifers tapped by tube wells No. 3 and No. 5 respectively. The formation loss coefficie[nts] were calculated found to be 190 m^{-2} secs. (17.6 ft^{-2} secs) and 238 m^{-2} secs (22 ft^{-2} secs) and the well loss coefficients to be 2784 m^{-5} sec^2 (7.33 ft^{-5} sec^2) and 3585 m^{-5} (9.44 ft^{-5} sec^2) for these two tube wells. Chemical analysis of water from the shallow tube wells was conducted (revealed the presence of total dissolved salts to be 201,175,202,214 and 256 mg/litre (Tube wells No. 1, 3, 4, 5 and 6). Of the existing six

shallow wells at I.I.T. Campus, tube well No.1 contributed very little to the supply and tube well No.6 did not contribute right from its inception. Tube well No. 2 has also been out of commission (at the time of writing this thesis) owing to the mechanical damage suffered due to sand pumping. Thus the discharge that could be provided for the Campus at a depression of about 5.4 to 6 m (18 to 20 ft.) stood at 3762000 lpd (8,36,000 gallons per day). These limitations brought down the supply to 46 per cent of the originally estimated figure (18,16000 gpd or 8172000 lpd) by Prof. WILKE at the inception time.

Investigations have also been carried out on the two deep tube wells located in the campus area. Data collected from others have also been presented. Pumping tests conducted in the campus for the deep aquifers revealed the transmissibility coefficients to be 447000 lpd/m (30050 gpd/ft) and 23,46,500 lpd/meter (1,57,300 gpd/ft) in the case of deep tube wells No. 1 and No. 2 respectively. The formation loss coefficients were found to be 172 m^{-2} secs (15.8 ft^{-2} secs) 87 m^{-2} secs (8 ft^{-2} secs) and the well loss coefficients to be 854 m^{-5} sec^2 (2.25 ft^{-5} sec^2) and 880 m^{-5} sec^2 (2.33 ft^{-5} sec^2) for these two tube wells. The discharges from these two tube wells are 94500 lpH and 153000 lpH (21000 gpH and 34000 gpH) respectively

at depressions of 6.45 m (21.5 ft.) and 6.25 m (20.75 ft.). Deep tube well No.1 has been temporarily shut down owing to the salinity of its water well above the standard (requirements). Chemical analysis of water from deep tube well No. 2 (which taps only deep aquifers) revealed a total dissolved solids content of 1230 mg/liter, chloride content of 550 mg/l, total hardness of 144 mg/l and total alkalinity of 220 mg/l. ~~Thus a~~ A comparison could be made between the quality of water from shallow and deep aquifers. In addition analyses of water samples at various consumer points within the campus have also been made to see the effect of deep tube well No. 2 on the main supply after being connected to the existing system.

Thus the thesis contains a detailed study of the existing sources of ground water supply to the I.I.T. Campus. A projection for the future needs with a suggested plan has also been included.

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Ground water is a potential source of water supply in the Gangetic basin where the hydrogeological framework is very conducive for its development. Of all the ground water provinces of India having an estimated storage of 37000×10^9 m^3 (around ten times the annual rainfall), the Gangetic basin has the major share. The Gangetic basin consists of Bhabar belt, Terai belt and Gangetic plains. In the Gangetic plains 2600 sq. kms of area out of 18000 sq. kms explored in Bihar and 5000 sq. kms. of area out of 24000 sq.kms explored in Uttar Pradesh are found to be good resources of ground water. By proper evaluation, development and management of the resources the ground water potential can be beneficially harnessed to meet several needs of the community living in this area. This fact has been very well recognized and considerable amount of work is being done in this direction as evidenced by a large number of tube wells already drilled and put into use and many more at several stages of planning and construction.

Kanpur city which lies in this region has wide scope and great need for ground water development from the point of view of even increasing demand for water due to the growth of population, expansion of industries and other reasons.

Ground water has been the only source of water supply to the campus of the Indian Institute of Technology at Kanpur as it has not been possible to get supply from the Ganga Canal which is the nearby source of surface water. Ground water continues to be the only source as no other source can be expected in the near future.

It is in this context that a study of the ground water potential of the campus is quite relevant from the point of view of providing a continuous supply of potable water for the campus community. Since already a decade has passed with the few tube wells installed in the early sixties, a study of the existing sources of supply will be of value in projecting the need as also in preparing the design for future years.

In the present study an attempt is made to discuss the quantitative and qualitative aspects of ground water potential at the campus based on the geological data, the results of pumping tests conducted on the shallow and

deep tube wells and the chemical analysis of water samples taken from them. The following are the specific objectives:

1) Characteristics of shallow and deep aquifers and a comparitive study of the same.

2) Chemical quality of water from them.

3) On the basis of a review of present situation and current investigations outlined above, a projection of future plans.

Apart from the aforementioned objectives the study provides us an opportunity to appreciate the usefulness and limitations of the standard methods of analysis of pumping test data in a practical situation as the current one.

For the topics covered in the present thesis the review of existing literature can be carried out conveniently under the following groupings:

1. Methodology for pumping tests
2. Water quality investigation
3. Work on Gangetic basin including Kanpur region.

1.1 Methodology for Pumping Tests:

Ever since the general equation of ground water flow

in a homogeneous isotropic medium was developed using Darcy's law (1856) and the principle of Conservation of mass, considerable work has been done in the direction of solving the equation and analysing pumping test data.

A major attempt towards an accurate mathematical analysis of the cone of depression was made by Theis (1935) who proposed the well known 'Non-equilibrium Formula' for ideal aquifers. To solve for the aquifer characteristics using the Non-equilibrium formula several indirect methods were proposed since the equation does not permit a direct solution. The first of these was a type curve solution proposed by Theis, in which, time-drawdown or distance-drawdown plot on a log-log paper is matched against a type curve showing the variation of W(u) Vs u. The aquifer parameters, T and S are then computed using the dual coordinates of a convenient match point.

Jacob (1950) devised a straight line method which fits most of the data except a few points at the beginning of the test. In this method the time-drawdown relation is plotted on a semilog paper and the best fitting line is drawn through the plots. The slope of the straight line helps in the determination of T, while its intercept with the axis of zero drawdown aids in the determination of S.

Another method was suggested by Chow (1952) where the drawdown data is plotted on a semilog paper and by drawing a tangent to the plotted curve at any convenient point, the slope of the tangent as well as the value of function F(u) help in the determination of T and S. ($F(u) = s/(\frac{\delta s}{\delta \log_{10} t}))$.

The afore-said methods relate to unsteady conditions of flow due to a continuation of the cone of depression. However, some cases of steady state or equilibrium conditions of flow may be attained during a pumping test as when the cone of depression intercepts a source of potential recharge. Under such conditions T could be directly computed by substituting the drawdown at any two points within the cone of depression in a simple equation by Theim (1906). In this case the well discharge is sustained by sources other than aquifer storage and the aquifer acts as a conduit transmitting water from the source of recharge to the well. Hence the coefficient of storage cannot be determined using this method.

Being a first attempt in a new direction, the Theis analysis was restricted in its scope and pertained only to an idealised set up fulfilling many assumptions like homogeneity, isotropy, infinite areal extent, etc. Natural geological conditions being generally complex, it

was soon recognized that Theis equation needed modifications so as to be applicable to various types of non-ideal conditions commonly obtained in the field. Several such nonideal conditions have been systematically analysed by a number of workers resulting in useful methods of analysis. One such is the case of partially penetrating wells for which Jacob (1945) devised a method by which corrections could be successively applied to observed drawdown data and aquifer parameters determined accurately. Hantush (1957) proposed two methods of analysis, a type curve method and a straight line method for computation of aquifer parameters in such a case.

For aquifers with lateral boundaries the well known 'method of images' which assumes that the boundary effects can be replaced by a suitable combination of image wells, is a simple tool for interpreting the boundary conditions.

Analyses of leaky acquifers have been carried out by Jacob (1946), Hantush (1956) and others. A relatively simple type curve solution has been devised by WALTON(1962) to determine T and S and also the leakage factor.

Detailed analysis of flow of water in a water table aquifer giving due consideration to delayed drainage was made by Boulton (1963). Jacob (1944) analysed the

problem of reduction of T due to reduction in saturated thickness with pumping and the consequent distortion of the cone of depression and devised a solution by which suitable corrections could be applied to the observed drawdown and the aquifer parameters determined. Papadopulos (1965) carried out the analysis of flow in infinite homogeneous anisotropic aquifers.

The conventional pumping tests relate to a set up in which the pumped well pierces only one aquifer. Frequently, however, wells are constructed tapping more than one aquifer. Papadopulos (1966) carried out an analysis of nonsteady flow to a well piercing two aquifers and devised an asymptotic solution to predict the water levels during a pumping test if the aquifer parameters are already known. DEWIEST (1966) studied the nonsteady flow to multiaquifer wells by means of the flow in a horizontal Heleshaw apparatus. The agreement between analytical solutions derived from a mathematical model neglecting well losses, and the experimental results from the physical analogue was found to be very good.

For cases of arbitrarily varying discharge Stallman (1962) devised a simple method which is essentially based on Theis equation. In this method the variable discharge is divided into a number of segments

based on which a family of type curves is constructed which helps in the determination of aquifer parameters. A more rigorous solution was attempted by Hantush (1964) for three common types of discharge variation in relation to leaky and nonleaky infinite aquifers. Sternberg (1967) devised a simple method using recovery data for an ideal aquifer with known variation of discharge.

To avoid the inherent disadvantages of the type curve method Jaeger (1959) suggested a method which helped in the determination of the parameters of an ideal aquifer considering the ratio relationship between the magnitudes of drawdown at any two intervals of time. Narasimhan (1968) extended this idea to include non-ideal conditions and proposed a method for determining the parameters of ideal, leaky or bounded aquifers.

Herbert (1968) analysed pumping tests by Resistance net-work analogue and now-a-days computer methods for pumping test analysis are becoming common. One such programming method was given by Saleem (1970).

Summing up, a number of tools are now available for the field worker to analyse data obtained from a variety of aquifer conditions. Although based on a level of mathematical knowledge beyond the scope of the general field worker, these methods have been reduced to simple

procedural forms which can be easily put into practice by him.

1.2 Water Quality Investigation:

Chemical analyses of water have been routine for more than a century; however, the successful correlation of water chemistry with the hydrologic and geologic environments or hydrogeochemistry is a more recent development. Modern hydro-geochemical studies in North America started with the work of CLARK (from about 1910 to 1925) and included a large number of chemical analyses, of water with geochemical interpretations. Piper (1944) gave a graphical procedure for geochemical interpretation of water analysis. The same author in 1953 gave another modified graphical method for geochemical interpretation of water analysis. Stiff (1951) interpretted chemical water analysis by means of patterns. Piper, et. al. (1953) described the principles of Cation exchange. Hem (1959) studied and interpreted the chemical characteristics of natural waters and concluded that there were no clear cut relationships between water quality and rock types in all areas of his investigation. DAVIS (1966) described the frequency distribution of dissolved solids in ground water in the areas of his study. Romero (1970)

described the movement of bacteria and viruses through porous media. Exhaustive studies of chemical ratios are largely done by Russian and French workers. The use of trace elements is done in many countries and detailed studies of various isotopes are done by workers in Japan, U.S.A., Russia and many other countries.

In India investigations on ground water quality form a part of the hydrogeological studies done by the Central Ground Water Board, Punjab Water Resources Directorate, Roorkee University and other state agencies. The Public Health Engineering Research Institute at Nagpur is doing considerable contribution to water quality investigation in India.

1.3 Work on Gangetic Basin Including Kanpure Region:

Though geophydrological studies in India began as early as 1804 to explore the possibilities of striking arterian wells in the Ganga basin, it was only in 1934 that large scale utilization of ground water began under the Ganga Valley Tube Well Irrigation Scheme in Uttar Pradesh. Systematic studies actually began in 1953 with the inception of the All India Ground Water Exploration Project.

Pathak (1954) gave a preliminary report on the ground water conditions and selection of sites for

exploratory bore holes in U.P.

The same author in 1955 described the ground water conditions in the alluvial tract of U.P. and gave his opinion that the shallow aquifers are under water table conditions while the deeper ones are under confined conditions. Nautiyal (1955) described the artesian water supply of Terai and Bhabar belts of U.P.

Taylor (1959) gave a general resume of ground water utilization and development and described the occurrence of ground water in eight ground water provinces of India. He dealt with the vast ground water reservoir of the Gangetic basin furnishing particulars of tube wells drilled in that area. Pandey, Raghav Rao and Karanth (1961) described the ground water potentialities of Bhabar formations of U.P. Mehta and Adyalkar (1962) studied the ground water potentialities of Terai and Bhabar zones forming the sloping plains along the Himalayan foothills. The scope of future work and utilization of the two belts more fully as extensive ground water provinces of India was recorded in the paper.

Chaturvedi and Pathak (1962) after analysing the pumping test data from certain areas of the Indo-Gangetic plains observed that varying geohydrological conditions occur in this area.

The same authors studied the flow of ground water towards wells in the viscinity of a perennial stream and presented their findings regarding the recharging boundary effect. They also studied the flow towards the pumping wells and optimum yield under varying geohydrological conditions.

Raghava Rao (1965) while working in Sharanpur district reported the average value of S and assigned a confined character to the aquifers. Singhal and Gupta (1966) after analyzing the pumping test data by various methods concluded that the deeper aquifers in Meerut - Muzaffarnagar areas are not under water table conditions, but they show leaky confined character locally. According to them, on a regional scale, possibly the shallow and deep aquifers may be interconnected representing a single hydraulic unit.

Perhaps the most comprehensive study of the upper Gangetic plain was made by Jones and Hoffman (1967) whose work dealt with the topography, climate, geology, tectonic framework, hydrology, hydrogeology and many other aspects. In particular, the aspects of geology and hydrogeology dealt with in their report are of interest for our present study. The characteristics of the three belts of the Gangetic basin, the hydrogeological characteristics of the aquifers in these belts and the

quality of ground water have also been furnished in the report.

Gupta (1968) made hydrogeological studies in Muzaffarnagar and parts of Meerut district, and tried to determine the relation of precipitation with that of rainfall penetration to the shallow ground water table by means of Jacob's method.

Mithal (1969) gave a reapraisal of ground water distribution and provinces in India. Chaterji (1969-70) reviewed the ground water investigations by G.S.I. since its inception in 1851. The particulars of ground water investigations done in U.P. and Bihar as given in the review are of interest for our present study.

Mithal, Singhal and Bajpai (1973) carried out hydrogeological studies in the Western parts of U.P. which revealed the occurrence of shallow aquifers at a depth of 6 to 24 m and deeper ones between 36 m and 121 m. Hydrogeological characteristics of the aquifers and the aquicludes were determined and an attempt was made to compute the recharge to ground water reservoir from rainfall by determining the correlation of rainfall with water level data. The rate of accretion to water table was found to be 21 per cent of the average annual rainfall.

WILKE (1966) made a study of the water supply of the I.I.T. Campus and gave a report which emphasizes a number of procedures to maintain adequate and safe water supply for the Campus. The report comprised of the estimates of daily water needs for different purposes; the performance of the tube wells No.1, 2 and 3 and the estimated yield from tube wells No. 4, 5, 6 which were proposed. Estimates of additional storage needs and methods of achieving the same were suggested and recommendations were made for maintaining the sources and the system in a satisfactory manner.

Gokhale (1971) presented a subsurface geohydrological picture for the campus area. A discussion on the properties of Gangetic aquifers was also included in the paper.

Verma (1973) collected data covering the shallow and deep aquifers of the Kanpur region. Hydrogeology of the principal aquifers of this region was studied and presented. Based on drilling log of shallow and deep drill holes subsurface pannel diagram for the principal aquifers were prepared and presented. Water table contours as also chemical quality contours were drawn for Kanpur region.

Very few systematic studies have so far been done on the quantitative and qualitative aspects of ground water potential of the I.I. T. Campus. The present study

CHAPTER 2

HYDROGEOLOGICAL CHARACTERISTICS OF SHALLOW AQUIFER SYSTEMS

The area under consideration forms a part of the Gangetic basin and lies in the Gangetic plains. For a basic understanding of the existing ground water supply sources it is essential to discuss the broader hydrogeological framework of the basin and then the I.I.T. Campus area in that context such that the nature of occurrence of aquifers and their characteristics would be better appreciated.

2.0 The Gangetic Basin:

The Gangetic basin extending between latitudes of 24° N and 30°N and longitudes 77°E and 88°E has an area of 250000sq. kms. It is directly connnected to the Himalayan uplift underlain by sedimentary rocks. As per the O.N.G.C. (Oil and Natural Gas Commission) report, the depth of the basin is 3000 m, although conflicting reports exist which place the depth around 11000 m based on gravity data. The entire basin consists of unconsolidated deposits of an alluvial source with intermittent continental elevations and scour trenches filled with

sand. Gradation of material from North to South and West to East exists.

The Northern belt or 'Bhabar' belt covers foothills region of Himalayas with 8 to 25 km width having a slope of 20 m per km. This has been the site of deposition of boulders, cobbles,gravel and sand dropped by rivers as the grade of the bed flattaned on the plain s. It is characterized by rolling topography with some reversal in slope., and extensive burried river deposits beneath it and the water table is 50 to 100 ft. below the land surface.

South of this belt and adjacent to it is the 'Terai' belt characterized by less relief and a land surface slope of 0.38 m per km. generally southward. This is immediately underlain by massive and extensive beds of clay. Water under sufficient artesian pressure is contained in sand and gravel beds occurring at depths of a few hundred feet so as to cause artesian wells. The boundary between this belt and the alluvial plain is less distinct but is generally taken as the line beyond which artesian flowing wells do not occur.

South of the 'Terai' belt is the alluvial plain called 'The Gangetic Plain' with alluvial deposits which are more fine textured. While typically fine

grained and thin bedded sandy sediments occur above a depth of 500 ft. in the Southern part of the region, the thickness and areal extent of flood basin clay deposits are very great (commonly more than 500 ft. thick and their lateral extent measured in squares of kms). Another feature of this belt is the occurrence of broad lenses of medium grained to fine grained sand which are crevasse deposits formed when breaks in the natural levees allow major diversion of the stream flow into flood basins during flood stage. The deposits may range from a few tens of feet in thickness and have an areal extent measured in terms of square kms. Lithologically they are almost isolated from meander belt deposits.

The hydrogeological frame work of the plain has the following characteristics:

1. The ground water reservoir formed by inter-connected sand bed aquifers is hydraulically continuous throughout most of the plain either by interlamination of braided stream and meander belt deposits or stream scour and subsequent backfill.

2. Complicated geometric patterns of aquifer distribution.

3. Longitudinal continuity of stream deposits.

4. Devious and narrow inter-connection which may severely restrict the ground water flow in many places.

5. Complicated regional ground water hydrology due to wide differences in aquifer thickness and occurrence of clay silt boundaries.

6. Directional continuity of aquifers which is Southward or Southeastward in the Northern half and East West directional continuity in the Southern half.

7. Excellent hydrogeologic setting for recharge along the northern marjin of the plain in the Bhabar belt which is due to coarse deposits and numerous streams that cross it to enter the plain.

2.1 Kanpur Region Including I.I.T. Campus:

The Kanpur region and in particular the area under study have similar characteristics mentioned above particularly fineness in texture, hydraulic continuity and East West directional continuity which is typical of the Southern half of the plain. Based on data collected from 45 shallow wells, the Kanpur region was divided

into five zones (Verma, 1973): Zone A mainly consisting of the area at I.I.T., Zone B extending from I.A.R.I. experimental station to L.L.R Hospital along the G.T. Road and covering an areal extent upto Nawabganj to the North of G.T. Road, Zone C covering an areal extent from Muir Mill to contonment area with N.E. boundary as river Ganga and S.E. boundary as G.T. Road, Zone D comprising of the Chakari area and Zone E covering part of Armapur Estate, Panki, Govindnagar and Juhi area. The I.I.T. area (Zone A) has the following geological features:

The sequence is one of clay with interlayers of sand (and occasomal Kankar) with silty clay material. The aquifers are of sand varying in size from 0.1 mm to 0.3 mm with main constituents as quartz, feldspar and mica. The thickness of each individual horizon is limited from 3 m to 6 m except for the lower horizon which reaches at places an individual thickness of about 15 m as in tube wells No.3 and No. 4. (Fig. 1). The aquifers in the campus area can be grouped into three main systems. In the first system upto 30 m depth extremely thin aquifers of silty size occur which pinch out in some portions of the area as could be evidenced from the figure. These aquifers thus pinch out and disappear in space. In the second system between 45 m to 60 m depth

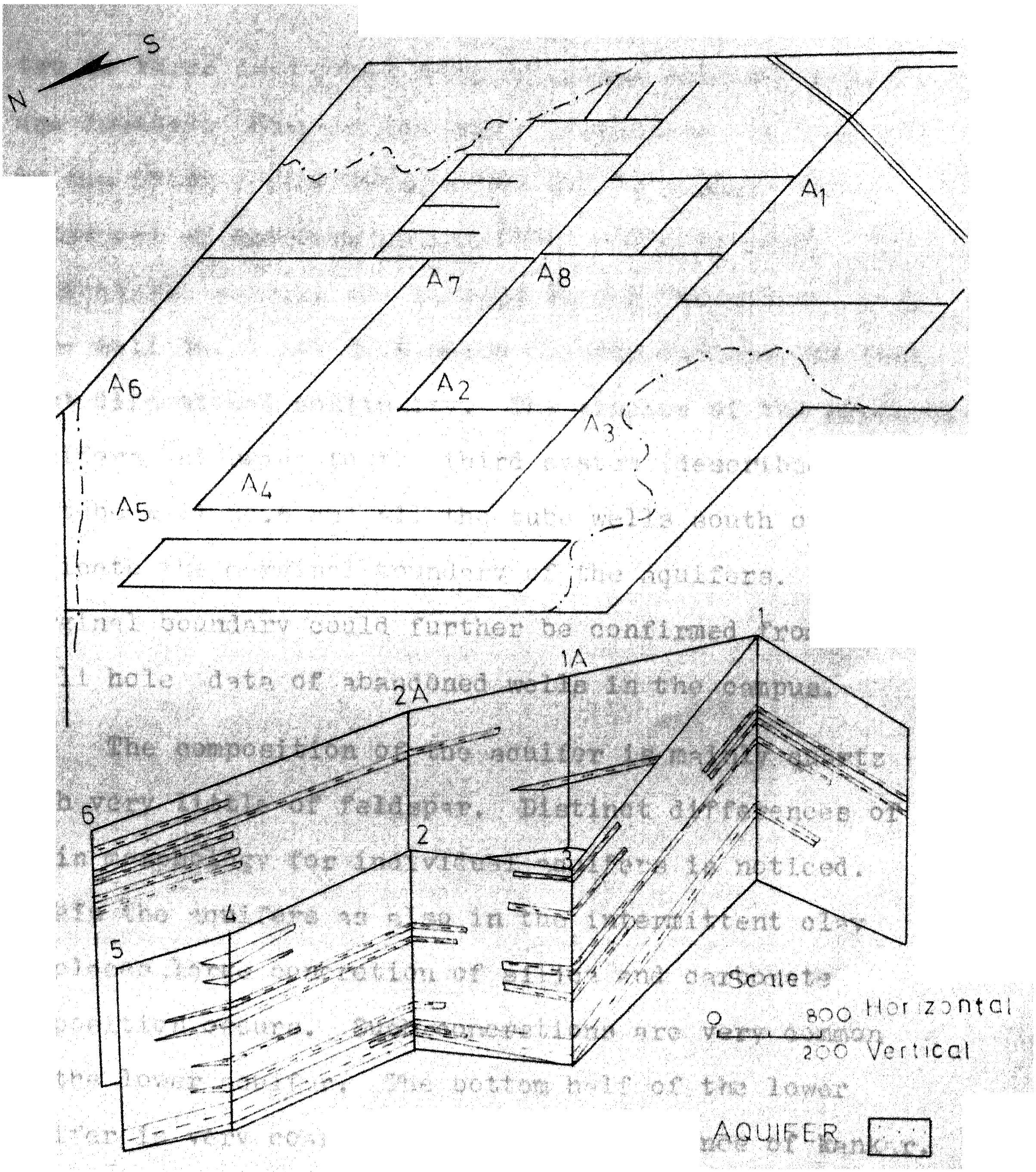


FIG.1 SUBSURFACE PANEL DIAGRAM OF ZONE "A"
(AFTER GOKHALE, 1971).

two to three individual thin stretches of sand in general are located. However, the major productive aquifers fall in the third system between 100 and 130 m where the thickness of aquifers range from 12 m to 15 m. The productive aquifers are present in all the wells except tube well No. 1 and No.6, which clearly reflects the East West directional continuity. The absence of the productive aquifers belonging to the third system (described above) in tube well No.6 and all the tube wells south of it indicate the marginal boundary of the aquifers. Such marginal boundary could further be confirmed from the drill hole data of abandoned wells in the campus.

The composition of the aquifer is mainly quartz with very little of feldspar. Distinct differences of grain morphology for individual aquifers is noticed. Within the aquifers as also in the intermittent clay at places, large concretion of silica and carbonate composition occurs. Such concretions are very common in the lower aquifer. The bottom half of the lower aquifer is very coarse grained with dominance of kankar.

Till recently the sources for the water supply in the campus were the shallow aquifers upto 130 m depth. From about April, 1974 the deep tube wells have been linked with the main supply network. In the present Chapter the details of the shallow tube wells are to be

discussed and the deep tube wells would be elaborated in the subsequent chapter.

There are six tube wells in the Campus tapping the shallow aquifers. In tube well No. 1 the third system is absent and hence the discharge is very poor. In tube well No. 6 also the third system is absent and it has been abandoned due to poor discharge and sand pumping. Tube wells No.3, No.4 and No. 5 give good discharge as they tap the third system which is most productive. Though tubewell No. 2 taps the thrid system, it has been abandoned due to sand pumping. The details of these tube well capacities are given below:

Table 1

Details of shallow tube wells

Tube well No.	Total thickness tapped	Discharge	
1	32' (9.6 m)	3000 gph	
2	48' (14.4 m)	Abandoned	
3	60' (18 m)	13000 gals/hr.	At draw-down of 18 to 20 ft.
4	87' (26.1 m)	12000 gpH	
5	70' (21 m)	10000 gpH	
6	41' (12.3 m)	Abandoned	

From the details given above it is clear that the tube wells No. 3, No.4 and No. 5 tapping the third system which is most productive are functioning satisfactorily. However their capacities as observed to date show a deviation of the order of 3 per cent in the case of tube well no. 3 and 50 per cent in the case of tube wells No.4 and No. 5 from the estimated capacities mentioned in WILKEY'S report.

2.2 Pumping Tests for Shallow Aquifers:

Pumping tests were conducted on tubewells No. 3 and No. 5 and from the analysis of the test data the coefficient of transmissibility, the formation loss coefficient and the well loss coefficient were determined.

2.3 Terminology:

The solution of the differential equation governing the radial flow to a well in an extensive aquifer as given by Theis is

$$s = \frac{Q}{4\pi T} W(u) \quad \text{where} \quad W(u) = \int_{\frac{r^2 S}{4Tt}}^{\infty} \frac{e^{-x}}{x}\, dx$$

$$\text{where} \quad u = \frac{r^2 S}{4Tt}$$

In field units the equations can be written as

$$s = \frac{114.6\ Q}{T}\ W(u)$$

$$u = \frac{1.87\ Sr^2}{Tt}$$

where s = drawdown in ft. measured in observation well due to constant discharge of pumped well.

Q = discharge of the pumped well in gallons per minute.

r = distance in ft. from the pumped well to the observation well.

S = coefficient of storage

t = time in days since pumping started.

and T = coefficient of transmissibility in gpd/ft.

Theis rearranged the above equation as follows and devised a graphical method for finding T and S.

$$\log s = \log W(u) + \log \frac{114.6\ Q}{T}$$

$$\log \frac{r^2}{t} = \log u + \log T/1.87S$$

A graph of s Vs $\frac{r^2}{t}$ is plotted on a log-log paper and this is matched with the type curve of W(u) Vs u also on a log log paper and from the coordinates of the match point the values of T and S are determined.

The above equations can also be arranged as:

$$\log s = \log W(u) + \log 114.6\ Q$$

$$\log t = \log \frac{1}{u} + \log \frac{1.87}{T} \frac{Sr^2}{}$$

A graph of s Vs t is plotted on a log log paper and it is matched with the type curve of W(u) Vs $\frac{1}{u}$ and from the coordinates of the match point the values of T and S are determined using the following equations:

$$T = \frac{114.6\ Q\ W(u)}{s}$$

$$S = \frac{uT\ t}{1.87\ r^2} \text{ where t is in days}$$

$$= \frac{uTt}{2693\ r^2} \quad \text{where t is in minutes.}$$

Jacob devised a straight line method in which the drawdown s Vs time is plotted on a semilog paper and from the slope of the line and its intercept on the axis of zero drawdown the values of T and S are determined using the following equations.

$$T = \frac{2.3\ Q}{4\pi\ \Delta s}$$

$$S = \frac{2.25\ T\ t_0}{r^2}$$

where Q is in cusecs or $m^3/sec.$

Δs is the drawdown change per log cycle of time

T is in $ft^2/sec.$ or $m^2/sec.$

r is in ft. or m

t_o is the time intercept with zero drawdown axis in seconds.

Theis recovery equation: Theis (1935) and Wenzel (1942) pointed out that the formation constants could be determined from the analysis of the recovery of a shut down well and gave the following equation:

$$s' = \frac{2.3\ Q}{4\pi T} \log \frac{t}{t'}$$

where Q' - discharge (cusecs or $m^3/sec.$)

s' - residual drawdown (ft. or m)

T - transmissibility ($ft^2/sec.$ or $m^2/sec.$)

t - time after pumping started

t' - time after pumping stopped.

This equation is represented by a straight line on semi-logarithmic paper and its slope allows for the determination of T using the following equation:

$$T = \frac{2.3\ Q}{4\pi \Delta s'}$$

where $\Delta s'$ is the residual drawdown change per log cycle of $\frac{t}{t'}$.

The above equations are based on the assumptions of homogeneity, isotropy and infinite areal extent of the aquifer, full penetration, nonleaky artesian condition, infinitesimal well diameter and instantaneous release of water from storage with the decrease in head.

As the thickness of the aquifers is usually small compared to its areal extent, the aquifers can be considered to be of infinite areal extent. The effect of nonhomogeneity is not so much felt as the area of influence extends with time. The area under study can be assumed to have nonleaky artesian condition and the well diameter of 6'' to 8'' can be considered as infinitesimal. As the aquifers are confined, the instantaneous release of water from storage is assumed to be fulfilled unlike water table aquifers where there is delayed drainage.

The well loss and the formation loss coefficients are determined by Hantush method and Walton's method.

Hantush method is based on the Jacob's equation

$$s = BQ + CQ^2$$ B - formation loss coefficient

C - well loss coefficient.

$$\frac{s}{Q} = B + CQ$$ (At a particular time since pumping started).

A graph of s Vs t is plotted on a semilog paper and the trend lines for each step are drawn. From this the values of s/Q for a particular value of t is determined for each step.

s/Q (as obtained above) is plotted against Q and a straight line graph is fitted through the points. The values of B and C are determined by taking the intercept on the s/Q axis and the slope of the line respectively.

In Walton's method the value of C is determined from the equation

$$C = \left(\frac{\Delta s_i}{\Delta Q_i} - \frac{\Delta s_{i-1}}{\Delta Q_{i-1}}\right) / \left(\Delta Q_{i-1} + \Delta Q_i\right)$$

where Δs_i, ΔQ_i - drawdown and discharge increments for i^{th} step.

and Δs_{i-1}, ΔQ_{i-1} - correspond to $i-1^{th}$ step.

2.4 Test Procedure (as recommended by WALTON)

Constant rate and variable rate well production tests are made to measure the productivity of a production well. In the constant rate well production test the production well is pumped at a constant rate for a period of at least 8 hrs. and water levels in the production well are measured at frequent intervals. In the variable

rate well production test or step drawdown test the production well is operated during successive periods usually about 1 hr. in duration at constant fractions of full capacity and the water levels in the production well are measured at frequent intervals. Sometimes the drawdown in nearby observation wells is measured during the well-production tests. The productivity of a well is generally expressed as the ratio of the pumping rate and the drawdown or Q/s.

I.S. 2800 recommends the following procedure: tests are conducted on the completed tubewell (a) to find out the performance of the tube well in regard to yield and drawdown, and (b) to select a suitable size and type of pump to be installed in the tube well.

Step draw down test (as per I.S. 2800)

This test is conducted by installing a test pump in the tube well temporarily and pumping out water at various speeds or by throttling the delivery sluice valve. At each rate of discharge pumping is carried out at least for 30 minutes. If the water level and discharge are found to be fluctuating, development is carried out for some more hours untill the discharge becomes steady and sand content is within tolerable limits. The specific capacities of the well for various pumping rates

is computed based on the step drawdown test data.

Aquifer performance test for exploratory tube wells:

This test is conducted after the tube well is allowed sufficient time to recoup its normal condition after the step drawdown test.

The well is pumped at a constant discharge rate and pumping water level is measured at close intervals of time during the initial stages of pumping. The measurement of water levels should be conducted according to any of the recognised methods such as graduated steel tape and electrical method. After pumping continuously at constant discharge for at least four hours, the pump is stopped and water level in the tube well is noted at very close intervals as it recoups. The process is continued untill the water level attains the original static water level in the pumped well. From the test data so obtained T and K are worked out. The storage coefficient and computation on well spacing can be done by constructing additional observation wells close by the test wells. WALTON'S procedure for conducting pumping tests which also satisfies the I.S.I. recommendations is adopted in the present study.

Constant discharge tests and step-draw-down tests were conducted on tube wells No. 3 and No. 5 and the data is presented in the following pages.

TABLE 2 TIME DRAWDOWN DATA FOR TUBEWELL NO.3

Time after pumping started (Minutes)	Drawdown (ft.)
1	14.00
5	14.50
10	15.00
15	15.00
20	15.50
30	16.00
45	16.50
60	16.50
90	17.00
120	17.50
150	17.50
180	18.00
210	18.00
240	18.50
300	18.50
360	18.50
420	19.00
480	19.00

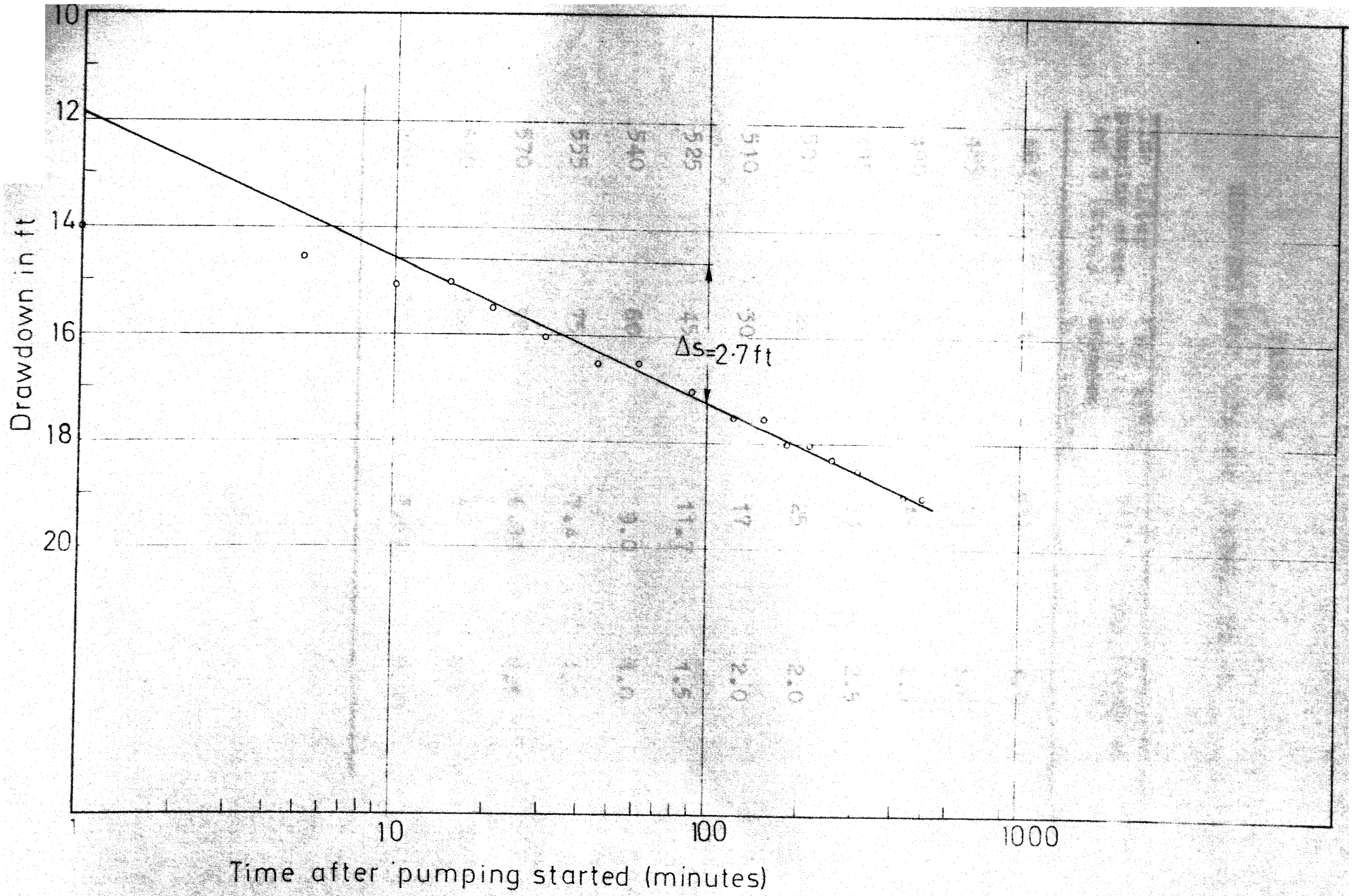


FIG.2 TIME DRAWDOWN GRAPH, TUBE WELL NO. 3 (JACOB'S METHOD)

TABLE 3

RECOVERY TEST DATA FOR TUBEWELL NO. 3

Time after pumping started t (min.)	Time after pumping stopped t'(minutes)	t/t'	Res. Drawdown (ft)
481	1	481	4.0
485	5	97	3.0
490	10	49	2.5
495	15	33	2.5
500	20	25	2.0
510	30	17	2.0
525	45	11.7	1.5
540	60	9.0	1.0
555	75	7.4	1.0
570	90	6.33	0.5
600	120	5	0.5
660	180	3.67	0.00

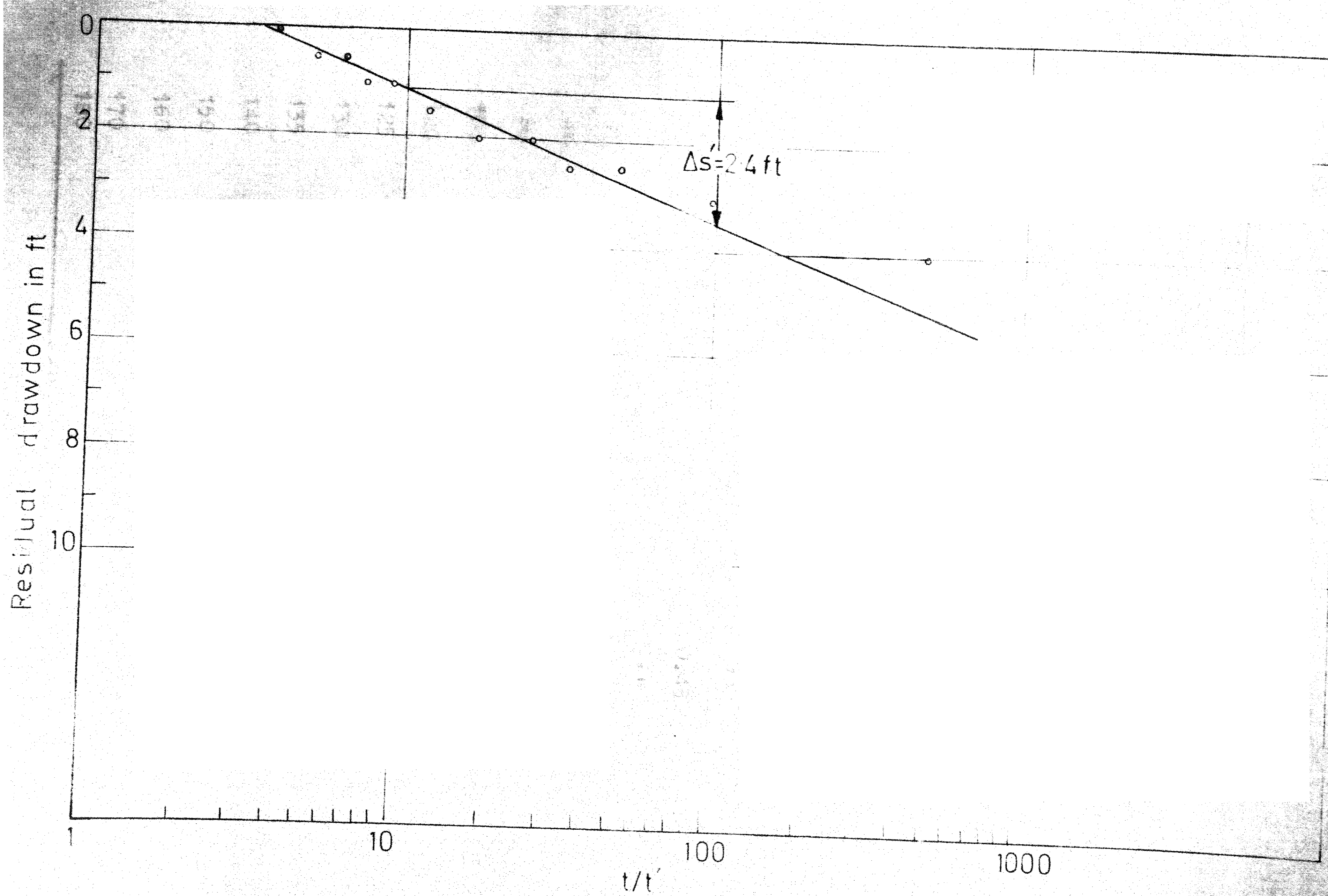


FIG.3 RECOVERY TEST , FOR TUBE WELL NO. 3

TABLE 4

TIME DRAWDOWN DATA FOR TUBEWELL NO.3 (STEP TEST)

Time since pumping started (minutes)	Drawdown (ft.)	Discharge (cusecs)
5	5.00	0.31
10	5.50	''
15	5.50	''
20	5.50	''
30	6.00	''
40	6.00	''
50	6.50	''
60	6.50	''
65	9.00	0.45
70	9.50	''
75	9.50	0.45
80	10.00	''
90	10.00	''
100	10.00	''
120	10.50	''
125	14.00	0.65
130	14.50	''
135	14.50	''
140	14.50	''
150	15.00	''
160	15.00	''
170	15.50	''
180	15.50	''

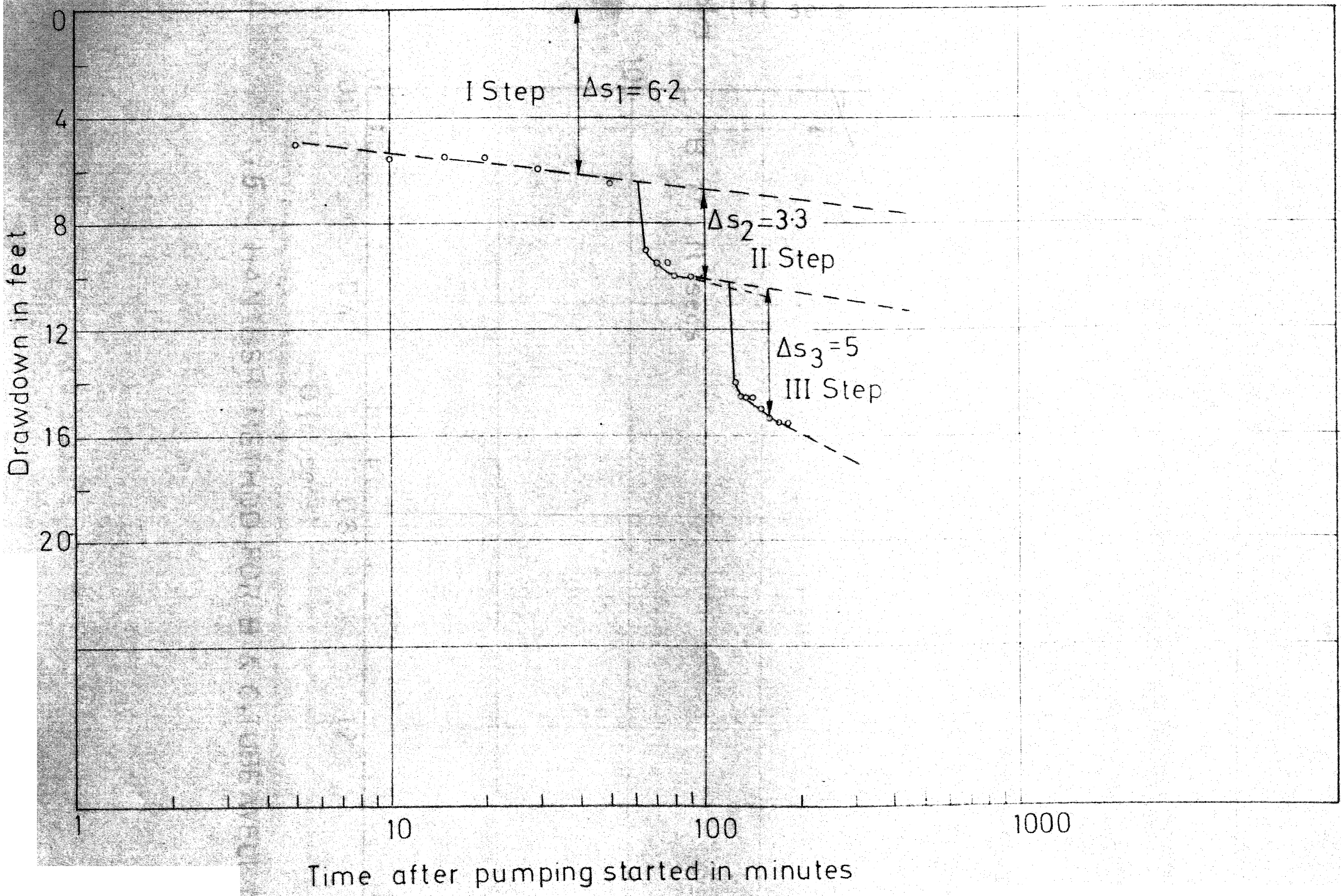
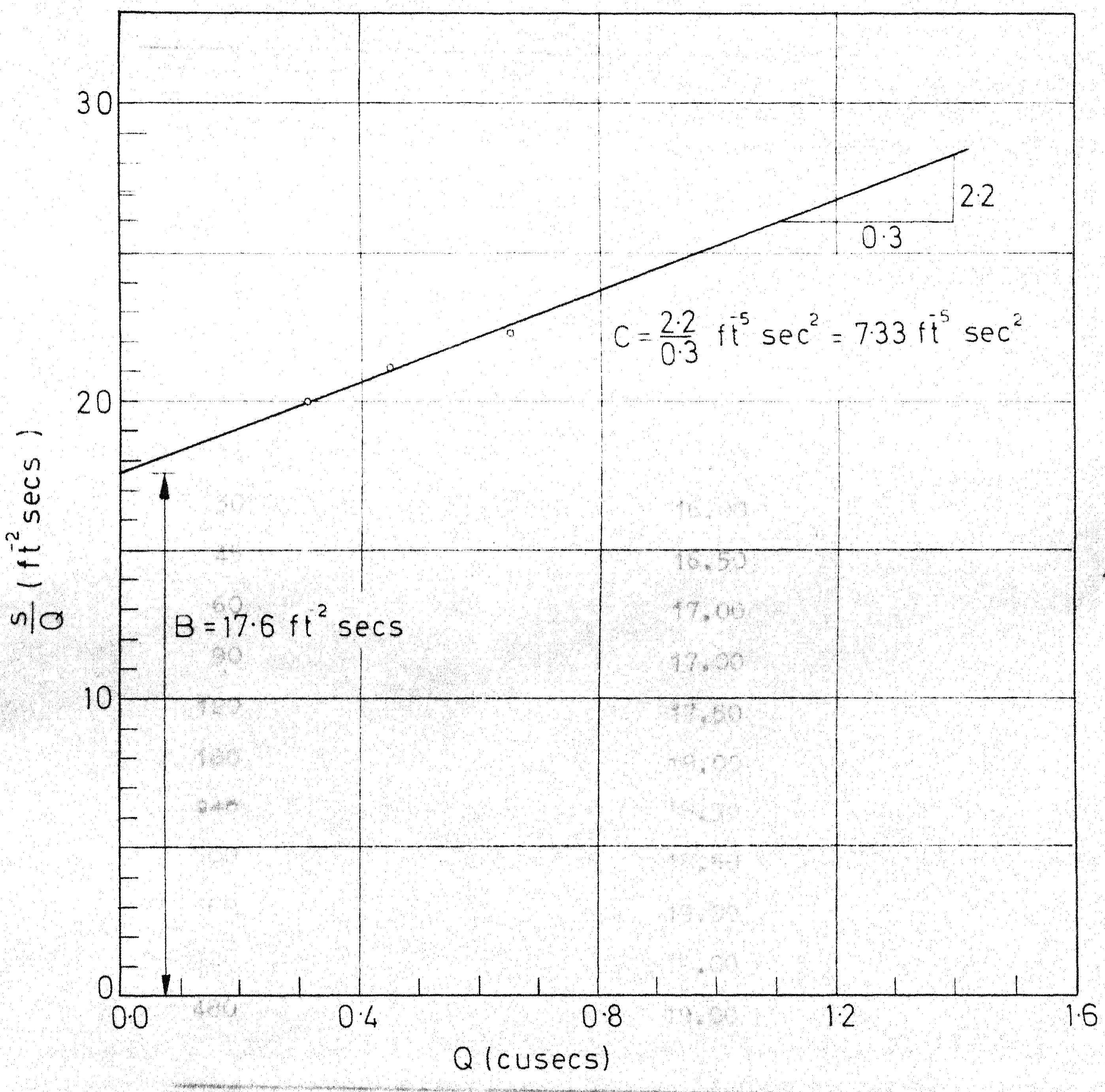


FIG 4 STEP TEST FOR TUBE WELL NO. 3



FIG·5 HANTUSH METHOD FOR B & C, TUBE WELL NO·3

TABLE 5

TIME DRAWDOWN DATA FOR TUBE WELL NO. 5

Time after pump started (Minutes)	Drawdown (ft.)
2	13.50
4	14.00
6	14.50
8	15.00
10	15.00
15	15.50
30	16.00
45	16.50
60	17.00
90	17.00
120	17.50
180	18.00
240	18.50
300	18.50
360	19.00
420	19.00
480	19.00

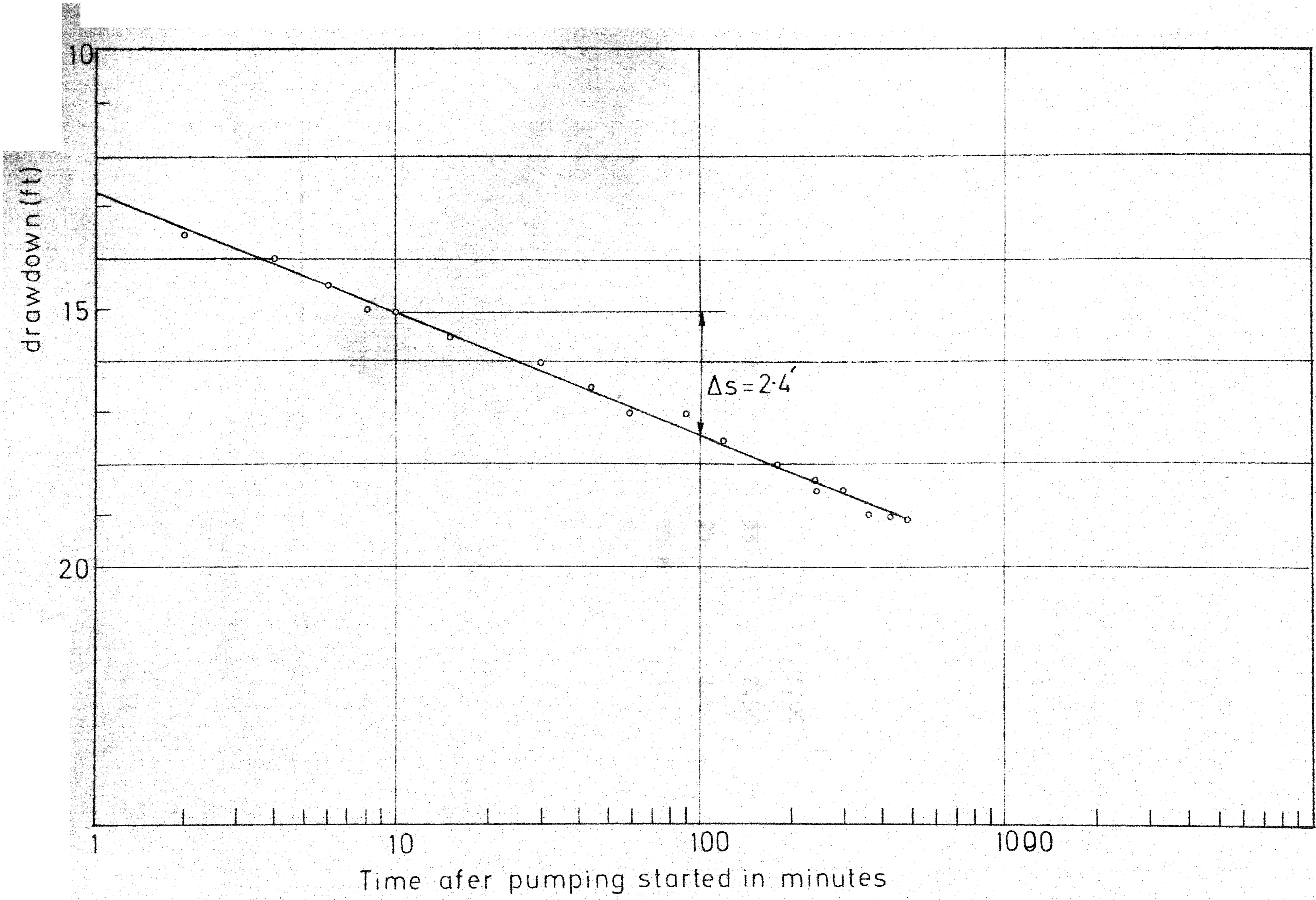


FIG.6 TIME DRAWDOWN GRAPH, TUBE WELL NO.5 (JACOB'S METHOD)

TABLE 6

RECOVERY TEST DATA FOR TUBE WELL NO. 5

Time since pumping started (Minutes)	Time since pumping stopped (Minutes)	t/t'	Drawdown (ft.)
482	2	241	5.00
484	4	121	4.00
486	6	81	3.50
488	8	61	3.00
490	10	49	3.00
495	15	33	2.50
500	20	25	2.00
505	25	20.2	2.00
510	30	17	1.50
525	45	11.6	1.00
540	60	9	1.00
555	75	7.4	0.50
570	90	6.33	0.50
585	105	5.50	0.50
600	120	5.00	0.50

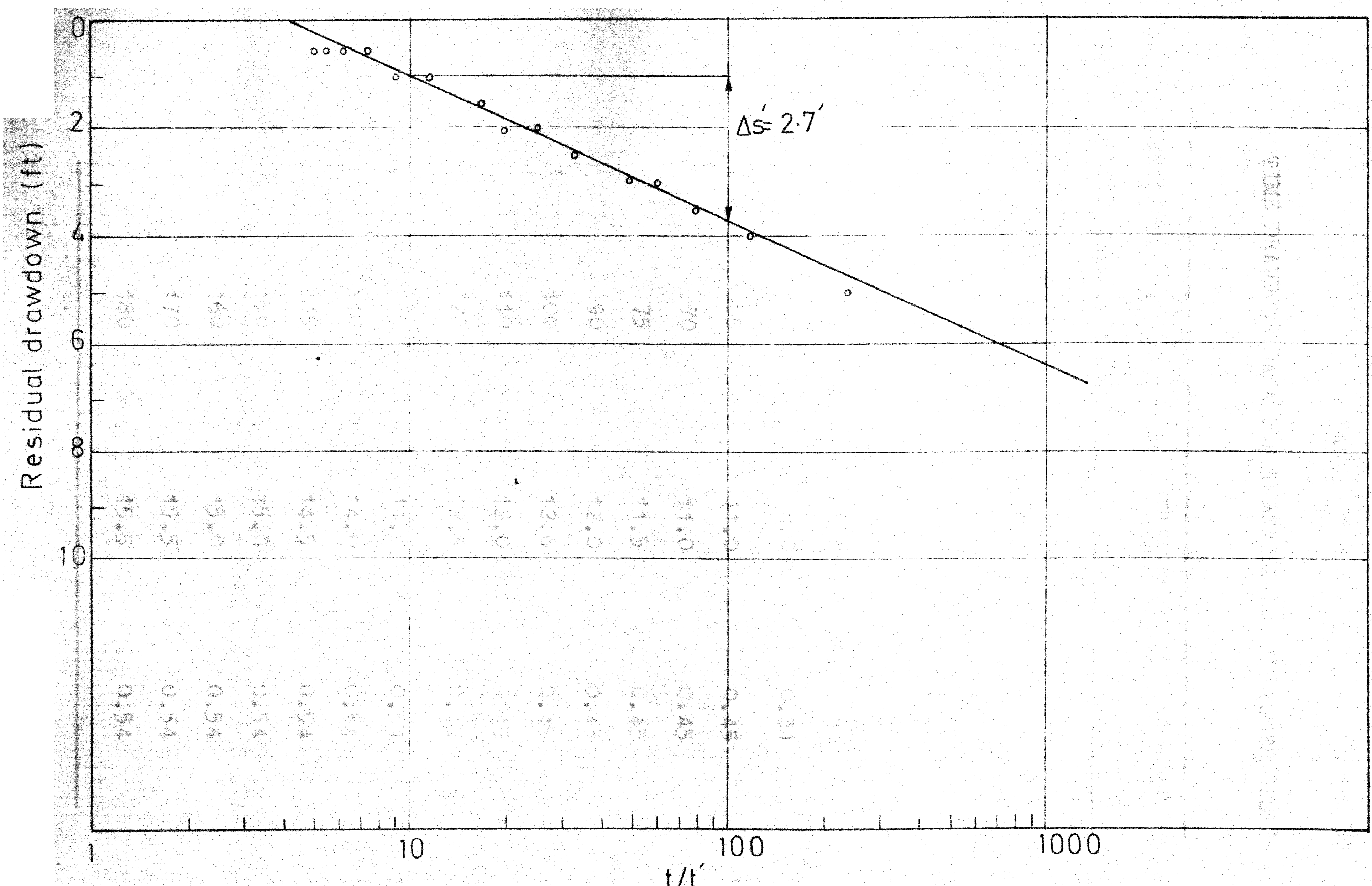


FIG. 7 RECOVERY TEST, TUBE WELL NO. 5

TABLE 7

TIME DRAWDOWN DATA FOR TUBEWELL NO. 5 (STEP TEST)

Step No.	Time since pumping started (minutes)	Drawdown (ft)	Discharge (cusecs)
I	5	7.0	0.31
	10	7.0	0.31
	15	7.5	0.31
	30	7.5	0.31
	40	7.5	0.31
	50	8.0	0.31
	60	8.0	0.31
II	65	11.0	0.45
	70	11.0	0.45
	75	11.5	0.45
	90	12.0	0.45
	100	12.0	0.45
	110	12.0	0.45
	120	12.5	0.45
III	125	14.0	0.54
	130	14.0	0.54
	135	14.5	0.54
	150	15.0	0.54
	160	15.0	0.54
	170	15.5	0.54
	180	15.5	0.54

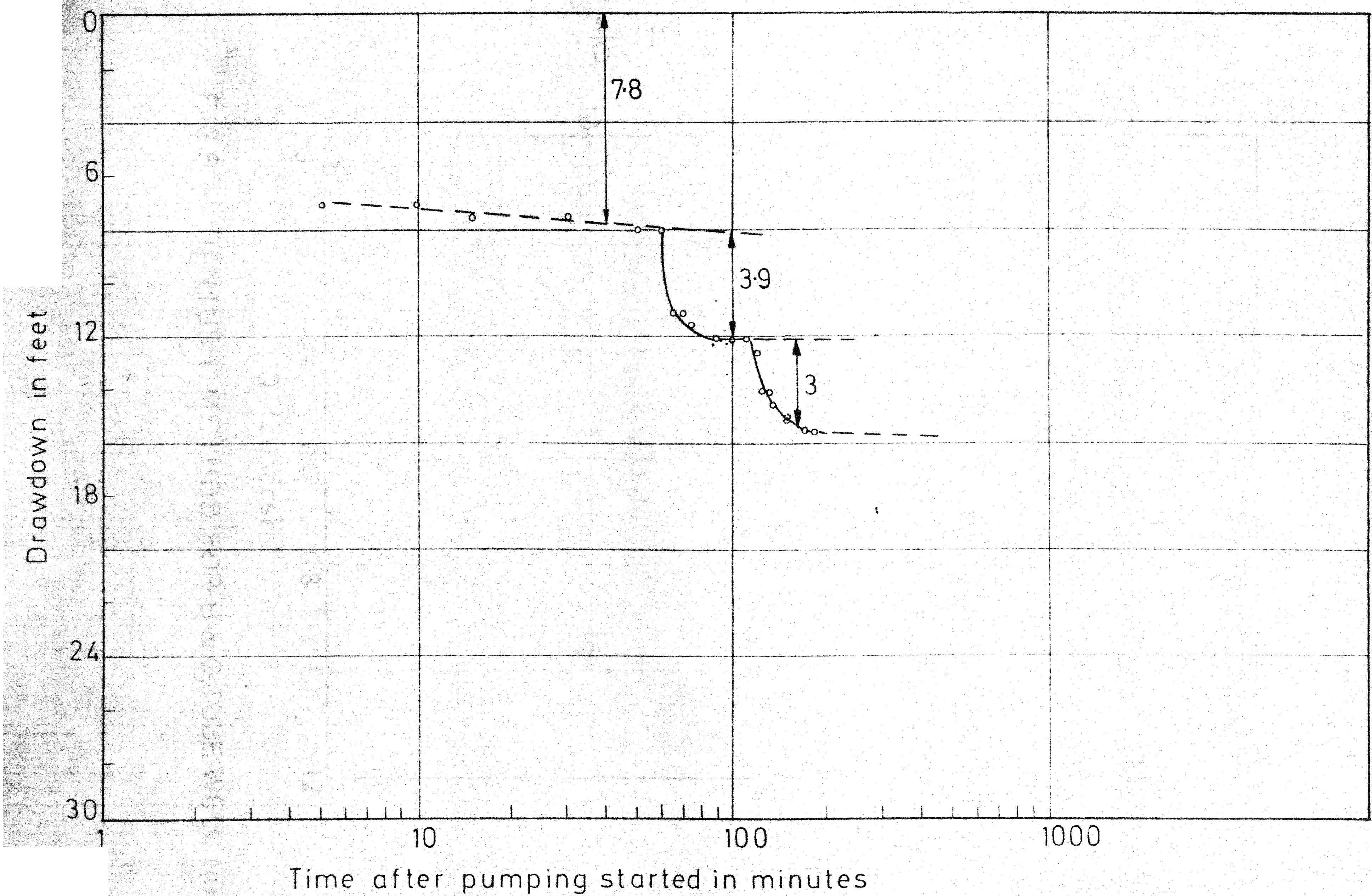


FIG.8 TIME DRAWDOWN GRAPH FOR STEP TEST, TUBE WELL NO 5

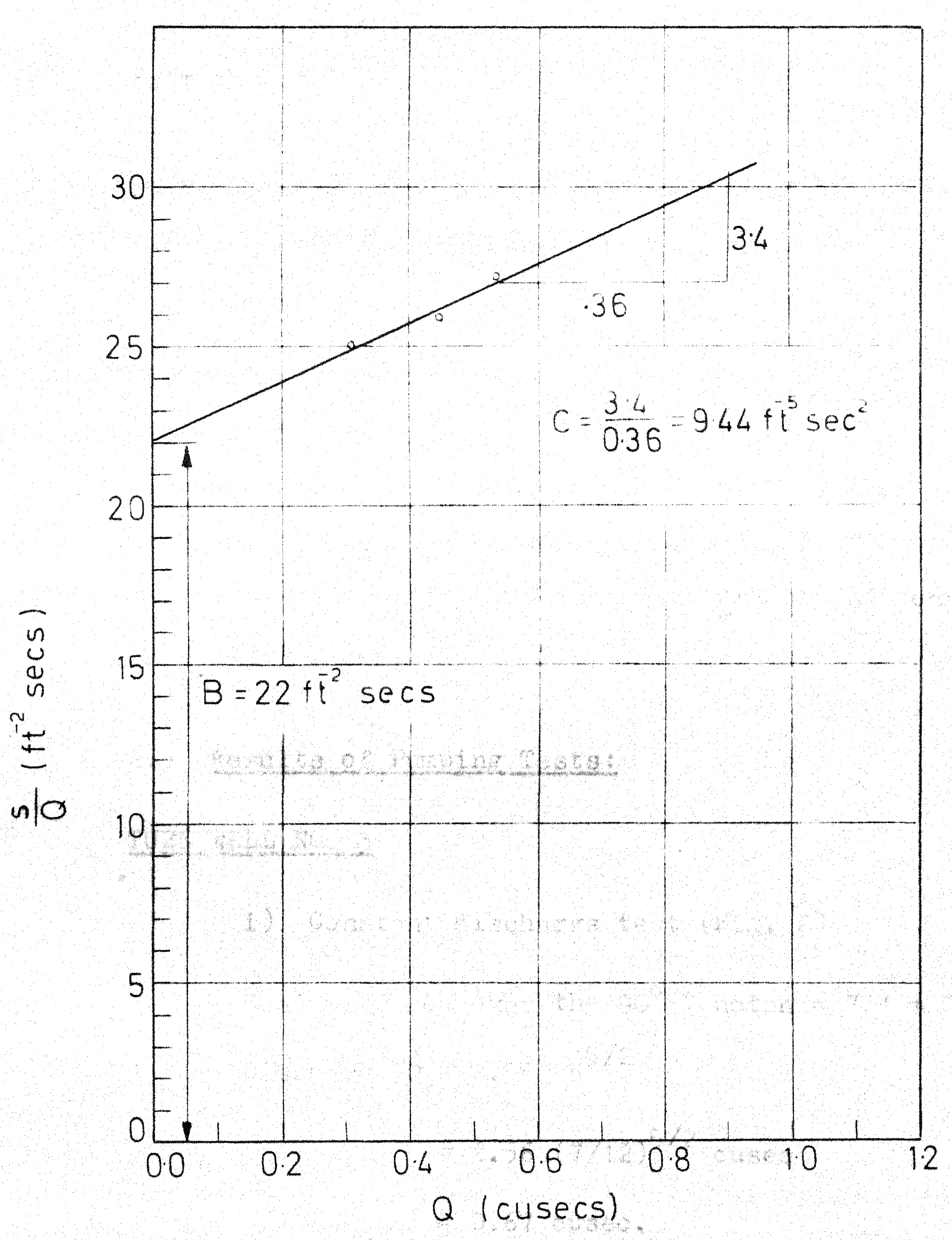


FIG 9 HANTUSH METHOD FOR B & C, TUBE WELL NO. 5

From the analysis of the test data the coefficient of transmissibility the well loss and formation loss coefficients were determined. The coefficient of storage could not be determined as there are no observation wells.

Also, to determine the barometric efficiency in order to make corrections in the pumping test data, water levels were regularly taken for tube well No.6 with corresponding atmospheric pressures for the same periods. However, the results as represented in Fig. 10 shows that the barometric efficiency is insignificant and hence could be ignored.

2.5 Results of Pumping Tests:

TUBE WELL NO. 3

i) Constant discharge test (Fig. 2)

Head measured over the 90° V notch = 7'' = 7/12 ft.

Discharge $Q = 2.56 \; H^{5/2}$

$$= 2.56 \; (7/12)^{5/2} \text{ cusec}$$

$$= 0.67 \text{ cusec.}$$

Δs from Fig. 2 = 2.7 ft.

Transmissibility $T = \dfrac{2.3Q}{4\pi \Delta s} = \dfrac{2.3 \times 0.67}{4 \times 3.14 \times 2.7} \; ft^2/sec.$

$= 0.045\ ft^2/sec.$

$= 24530$ gpd/ft. (365000 l.p.d./m)

Field permeability, $K = (T/b)$

where b = thickness of aquifer tapped = 60 ft.

$$K = T/b = \frac{24530}{60}\ gpd/ft^2$$

$= 408.8$ g.pd $/ft^2$ (20000 lpd/m^2)

ii) Recovery Test (Fig. 3)

$\Delta s'$ from graph = 2.4 ft.

$$T = \frac{2.3Q}{4\pi\Delta s'} = \frac{2.3 \times 0.67}{4 \times 3.14 \times 2.4}\ ft^2/sec = 0.052\ ft^2/sec.$$

$= 27600$ gpd/ft (410000 lpd/m)

$$K = T/b = \frac{27600}{60}\ gpd/ft^2$$

$= 460\ gpd/ft^2$ (22800 lpd/m^2)

$$T_{av} = \frac{24530 + 27600}{2}\ gpd/ft = 26065\ gpd/ft$$

(387500 lpd/m)

$$K_{av} = \frac{408.8 + 460}{2}\ gpd/ft^2 = 434.4\ gpd/ft^2$$

(21400 lpd/m^2)

iii) Step-drawdown test (Figs.4 and 5)

Table 8

Hantush Method for Tube Well No. 3

Step No.	Discharge Q(cusecs)	Drawdown s(ft.)	s/Q
1	0.31	6.2	20.0
2	0.45	9.5	21.11
3	0.65	14.5	22.30

From graph (Fig. 5), B = 17.6 ft^{-2} secs,
(190 m^{-2} secs.)

C = 7.33 ft^{-5} sec^2
(2784 m^{-5} sec^2)

Table 9

WALTON'S Method for Tube Well No. 3

Step No.	ΔQ (cusec)	Δs (ft.)	$\frac{\Delta s}{\Delta Q}$
1	0.31	6.2	20.00
2	0.14	3.3	23.57
3	0.20	5.0	25.00

$$C_{12} = \left(\frac{\Delta s_2}{\Delta Q_2} - \frac{\Delta s_1}{\Delta Q_1}\right) / (\Delta Q_1 + \Delta Q_2) = \frac{23.57 - 20}{0.31 + 0.14} \text{ ft}^{-5} \text{ sec}^2$$

$$= 7.93 \text{ ft}^{-5} \text{ sec}^2 \quad (3010 \text{ m}^{-5} \text{ sec}^2)$$

$$C_{23} = \left(\frac{\Delta s_3}{\Delta Q_1} - \frac{\Delta s_3}{\Delta Q_2}\right) / (\Delta Q_1 + \Delta Q_2) = \frac{25-23.57}{0.15+0.2} \text{ ft}^{-5} \text{ sec}^2$$

$$= 4.08 \text{ ft}^{-5} \text{ sec}^2 \quad (1535 \text{ m}^{-5} \text{ sec}^2)$$

Tube Well No. 5 (Fig. 6)

i) Constant discharge test:

Head measured over V 'notch = 6.4" = $\frac{6.4}{12}$ ft.

Discharge $Q = 2.56 H^{5/2} = 2.56 \times (\frac{6.4}{12})^{5/2}$

$= 0.53$ cusec.

Δs from graph (Fig. 6) = 2.4 ft.

$$T = \frac{2.3Q}{4\pi \Delta s} = \frac{2.3 \times 0.53}{4 \times 3.14 \times 2.4} \text{ ft}^2/\text{sec} = 0.04 \text{ ft}^2/\text{sec}.$$

$$= 21600 \text{ gpd/ft.} \quad (321500 \text{ lpd/m})$$

Field permeability $K = (T/b) = \frac{21600 \text{ gpd/ft}^2}{70}$

$$= 308.6 \text{ gpd/ft}^2 \quad (15309 \text{ lpd/m}^2)$$

ii) Revovery test (Fig. 7)

$\Delta s'$ from graph = 2.7 ft.

$$T = \frac{2.3\ Q}{4\pi\ \Delta s'} = \frac{2.3 \times 0.53}{4 \times 3.14 \times 2.7}\ ft^2/sec. = 0.036\ ft^2/sec.$$

$$= 19400\ gpd/ft\ (289000\ lpd/m)$$

$$K = (T/b) = \frac{19400}{70}\ gpd/ft^2 = 271.4\ gpd/ft^2$$

$$(13700\ gpd/m^2)$$

T_{av} = 20500 gpd/ft (305250 lpd/m)

K_{av} = 290 gpd/ft^2 (14500 lpd/m^2)

iii) Step-draw-down Test: (Figs. 8 and 9)

Hantush Method

Table 10

Hantush Method for Tube Well No. 5

Step No.	Discharge Q (cusecs)	Drawdown s (ft)	s/Q
1	0.31	7.8	25.16
2	0.45	11.7	26.00
3	0.54	14.7	27.20

From the graph (Fig. 9), $B = 22\ ft^{-2}$ secs

$(238\ m^{-2}$ secs)

$C = 9.44\ ft^{-5}\ sec^2$

$(3585\ m^{-5}\ sec^2)$

Table 11

WALTON'S Method for Tube Well No. 5

Step No.	ΔQ (cusecs)	Δs (ft.)	$\frac{\Delta s}{\Delta Q}$
1	0.31	7.8	25.16
2	0.14	3.9	27.86
3	0.09	3.0	33.33

$$C_{12} = \left(\frac{\Delta s_2}{\Delta Q_2} - \frac{\Delta s_1}{\Delta Q_1}\right)/(\Delta Q_1 + \Delta Q_2) = \frac{27.86 - 25.16}{0.31 + 0.14}\ ft^{-5}\ sec^2$$

$$= 6\ ft^{-5}\ sec^2\ (2280\ m^{-5}\ sec^2)$$

$$C_{23} = \left(\frac{\Delta s_3}{\Delta Q_3} - \frac{\Delta s_2}{\Delta Q_2}\right)/(\Delta Q_2 + \Delta Q_3) = \frac{33.33 - 27.86}{0.23}\ ft^{-5}\ sec^2$$

$$= 23.7\ ft^{-5}\ sec^2\ (9000\ m^{-5}\ sec^2)$$

Table 12

2.6 Chemical Characteristics of Water from Shallow Tube Wells

Chemical characteristic	Tube well No. 1	3	4	5	6	*Max. Allowed
CO_3 (Mg/l)	145	Nil	Nil	Nil	Nil	Not specified
HCO_3 (Mg/l)	350	565	542	547	485	Not specified
Cl (Mg/l)	10	44	45	53	38	250
T.D.S. (mg/l)	201	175	202	214	256	1000
pH	8.1	7.7	8.0	7.9	8.0	6.6 to 8

The table indicates the chemical characteristics for the ground water samples collected from the shallow tube wells. Comparing the characteristics of ground water from shallow wells with the specifications given above, it can be seen that T.D.S. and Cl fall well within the range in all the cases while pH is slightly more than the specified value in the case of tube well No. 1 only. Hence water from shallow tube wells is quite suitable for drinking.

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* Kshirsagar, S.R. (1962): Water Supply Engineering, Vol.1, Roorkee Publishing House, Roorkee pp. 159-160.

TABLE 13

DAILY WATER LEVEL OBSERVATIONS IN TUBEWELL NO. 6

Date	Water level m	Atmospheric Pressure (Inches of Mercury)
1/2	11.2	29.85
2/2	11.22	29.88
3/2	11.22	29.88
4/2	11.24	29.88
5/2	11.25	29.9
6/2	11.25	29.88
7/2	11.26	29.90
8/2	11.26	29.88
9/2	11.24	29.90
10/2	11.24	29.86
11/2	11.22	29.90
12/2	11.22	29.88
13/2	11.23	29.84
14/2	11.24	29.84
15/2	11.26	29.86
16/2	11.26	29.88
17/2	11.26	29.90
18/2	11.27	29.90
19/2	11.27	29.90
20/2	11.26	29.90

Contd.

Contd. Table 13

Date	Water level (m)	Atmospheric Pressure (Inches of Mercury)
21/2	11.26	29.9
22/2	11.26	29.82
23/2	11.27	29.80
24/2	11.27	29.82
25/2	1. 29	29.85
26/2	11.30	29.82
27/2	11.30	29.82
28/2	11.31	29.82
1/3	11.305	29.82
2/3	11.305	29.78
3/3	11.305	29.80
4/3	11.320	29.70
5/3	11.325	29.60
6/3	11.320	29.70
7/3	11.320	29.70
8/3	11.340	29.70
9/3	11.355	29.72
10/3	11.345	29.74
11/3	11.330	29.74
12/3	11.320	29.80
13/3	11.330	29.83
14/3	11.330	29.85

Contd.

Contd. Table 13

Date	Water level (m)	Atmospheric Pressure (Inches of Mercury)
15/3	11.36	29.90
16/3	11.37	29.84
17/3	11.38	29.77
18/3	11.385	29.75
19/3	11.400	29.64
20/3	11.41	29.68
21/3	11.415	29.80
22/3	11.42	29.70
23/3	11.43	29.70
24/3	11.445	29.60
25/3	11.435	29.60
26/3	11.480	29.60
27/3	11.470	29.74
28/3	11.470	29.75
29/3	11.480	29.75
30/3	11.50	29.72
31/3	11.52	29.70
1/4	11.535	29.70
2/4	11.550	29.68
3/4	11.570	29.70
4/4	11.59	29.70
5/4	11.60	29.70

Contd.

Date	Water level (m)	Atmospheric Pressure (Inches of Mercury)
6/4	11.60	29.70
7/4	11.60	29.68
8/4	11.61	29.60
9/4	11.61	29.64
10/4	11.62	29.65
11/4	11.63	29.62
12/4	11.65	29.60
13/4	11.655	29.62
14/4	11.660	29.65
15/4	11.665	29.70
16/4	11.680	29.70
17/4	11.690	29.70
18/4	11.710	29.70
19/4	11.710	29.72
20/4	11.715	29.71
21/4	11.720	29.74
22/4	11.730	29.73
23/4	11.735	29.74
24/4	11.740	29.75
25/4	11.750	29.72
26/4	11.76	29.70
27/4	11.77	29.70
28/4	11.79	29.67

Contd.

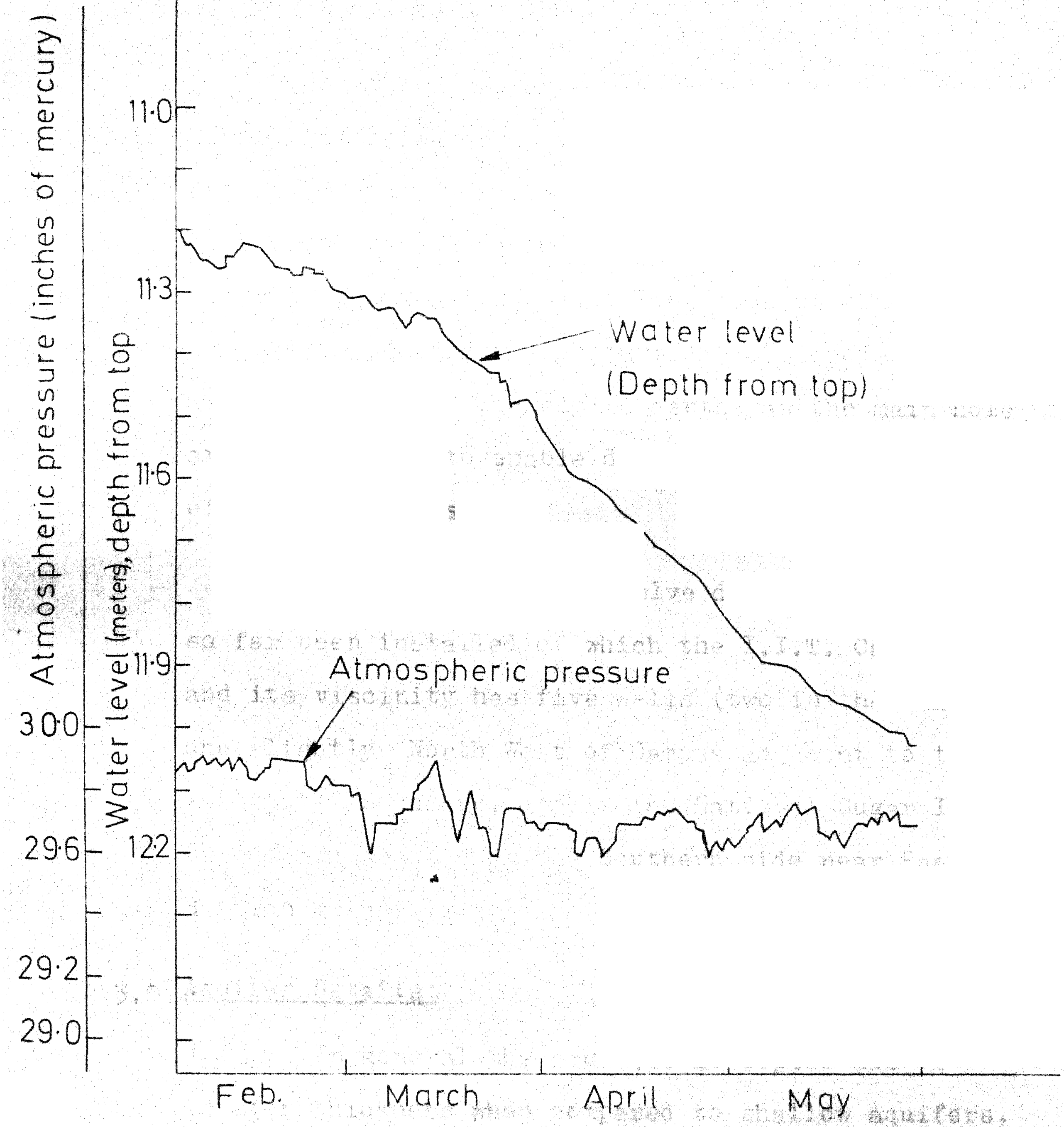
Contd. Table 13

Date	Water level (m)	Atmospheric Pressure (Inches of Mercury)
29/4	11.81	29.60
30/4	11.82	29.64
1/5	11.83	29.62
2/5	11.85	29.65
3/5	11.86	29.63
4/5	11.87	29.64
5/5	11.88	29.68
6/5	11.89	29.70
7/5	11.89	29.72
8/5	11.89	29.68
9/5	11.89	29.24
10/5	11.89	29.76
11/5	11.90	29.73
12/5	11.90	29.75
13/5	11.91	29.72
14/5	11.92	29.67
15/5	11.93	29.66
16/5	11.94	29.68
17/5	11.94	29.65
18/5	11.95	29.64
19/5	11.95	29.68
20/5	11.96	29.70
21/5	11.96	29.70
22/5	11.96	29.72

Contd.

Contd. Table 13

Date	Water Level (m)	Atmospheric Pressure (Inches of mercury)
23/5	11.97	29.70
24/5	11.97	29.74
25/5	11.98	29.71
26/5	11.99	29.73
27/5	11.99	29.69
28/5	12.00	29.70
29/5	12.00	29.72
30/5	12.01	29.68
31/5	12.02	29.70



FIG·10 DAILY WATER LEVEL FLUCTUATION IN TUBE WELL NO·6

CHAPTER 3

HYDROGEOLOGICAL CHARACTERISTICS OF DEEP AQUIFERS

In the Gangetic plains, recent trend of development of groundwater is through tapping of deep aquifers around 300 m or more. All the drilling and development operations for these tube wells are undertaken by the Central Ground Water Board. For some of the wells meant for study, in addition to the main drill holes, observation holes tapping the entire depth as the main hole are also placed to enable determination of both S and T of the formations.

In Kanpur region, twelve deep tube wells have so far been installed of which the I.I.T. Campus area and its viscinity has five wells (two in the Campus, one slightly North West of Campus adjacent to the Institute boundary, one in the National Sugar Institute Campus and another on the Southern side near Panki Power Station area).

3.0 Aquifer Details:

In general the aquifers at depths are of greater thickness when compared to shallow aquifers,

the most productive ones lying between 290 m and 400 m. They are multilayered aquifers with the gap between individual aquifers varying from about 12 to 60 m. They vary from medium and coarse sand to gravel size inter-calated with silty clay or clay. The table indicates the details of all the five tube wells.

Table 14

Details of Deep Tube Wells

Location	Depth (m)	Thickness of aquifer (m)	Discharge in gallon (per hour)
IIT(Deep Tube Well No.1)	416	123.85	21000 (95500 lpH)
IIT(Deep Tube Well No. 2)	399.63	42.30	34000 (153000 lpH)
N.S.I	363.74	60.0	34000 (153000 lpH)
Artificial Limbs Factory	394.1	48.0	not available
Panki	508 m	Not available	

The deep tube well No. 1 in the IIT Campus (near Girl's Hostel) is provided with an observation

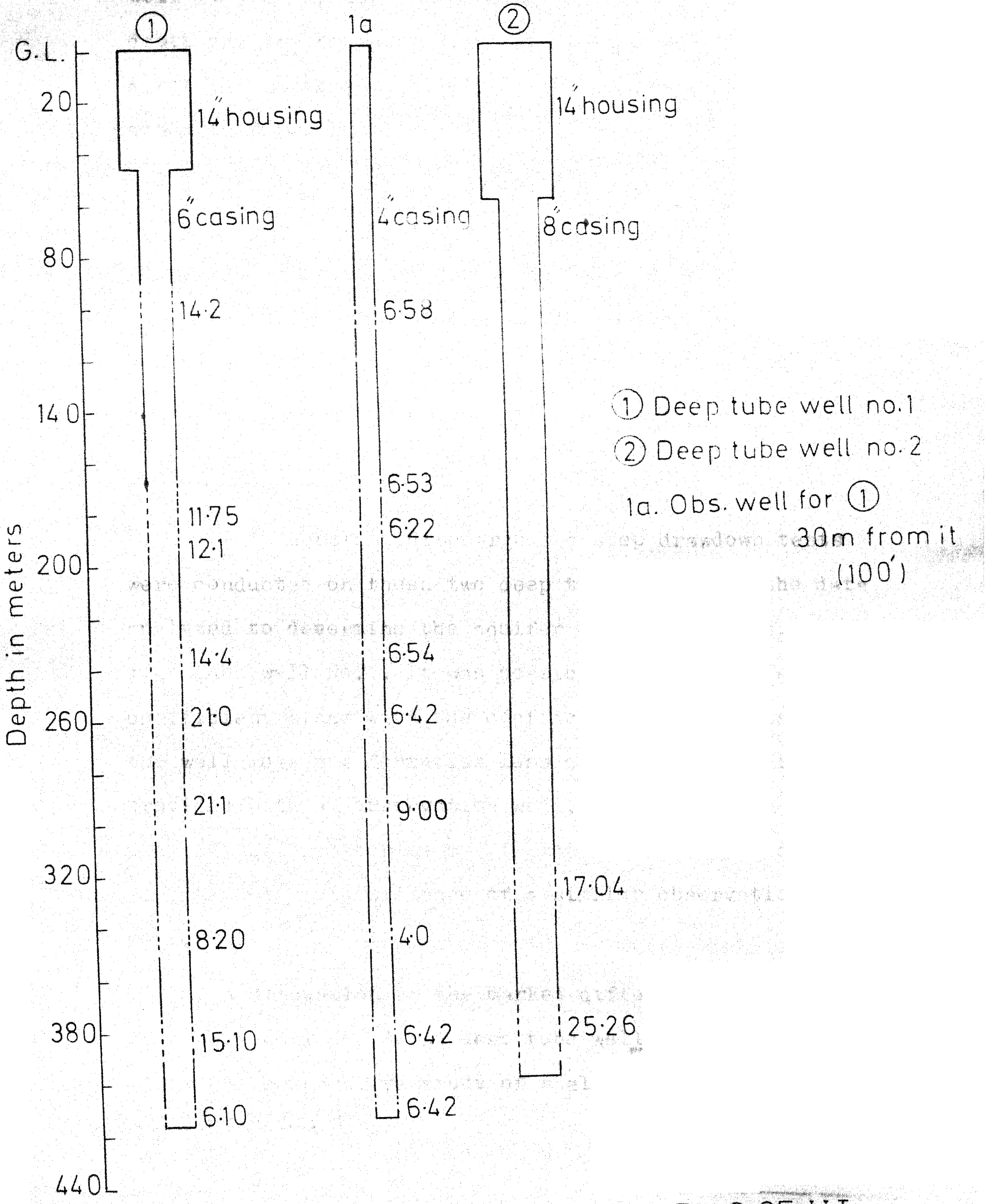


FIG.11 ASSEMBLY DETAILS OF DEEP TUBE WELLS OF I.I.T.

well 4'' in diameter extending to almost the same depth and 100 ft. away from the pumping well. It taps a total thickness of 123.85 m at various depths as shown in Fig. 11.

The deep tubewell No.2 is located near the Railway line between the shallow tube wells No. 5 and No.6. It taps two aquifers consisting of gravel of total thickness of 42.3 m as shown in Fig. 11. This has been recently connected to the main pipe network of the campus.

3.1 Pumping Tests:

Both constant discharge and step drawdown tests were conducted on these two deep tube wells and the data analyzed to determine the aquifer characteristics. For deep tube well No.1, it was possible to find the storage coefficient along with the coefficient of transmissibility, the well loss and formation loss coefficients as it is provided with an observation well, while for deep tube well No. 2, the storage coefficient could not be determined due to non-existence of a similar observation well.

A discussion on the marked differences between deep tube well No. 1 and deep tube well No. 2 is given under the comparative study of shallow and deep aquifers in Chapter No. 4.

TABLE 15

TIME DRAWDOWN DATA FOR OBS. WELL 100 FT. FROM DEEP TUBE WELL No.1
(8 hrs. duration)

Time after pumping started (minutes)	Drawdown (meters)	Time after pumping started (minutes)	Drawdown (meters)
2	0.50	135	2.31
4	0.97	150	2.35
6	1.16	165	2.38
8	1.32	180	2.42
10	1.40	210	2.48
15	1.51	240	2.53
20	1.60	270	2.57
25	1.67	300	2.62
30	1.74	330	2.66
35	1.79	360	2.69
40	1.84	390	2.72
45	1.90	420	2.74
50	1.95	480	2.76
60	2.02		
70	2.08		
80	2.13		
90	2.17		
100	2.21		
110	2.24		
120	2.27		

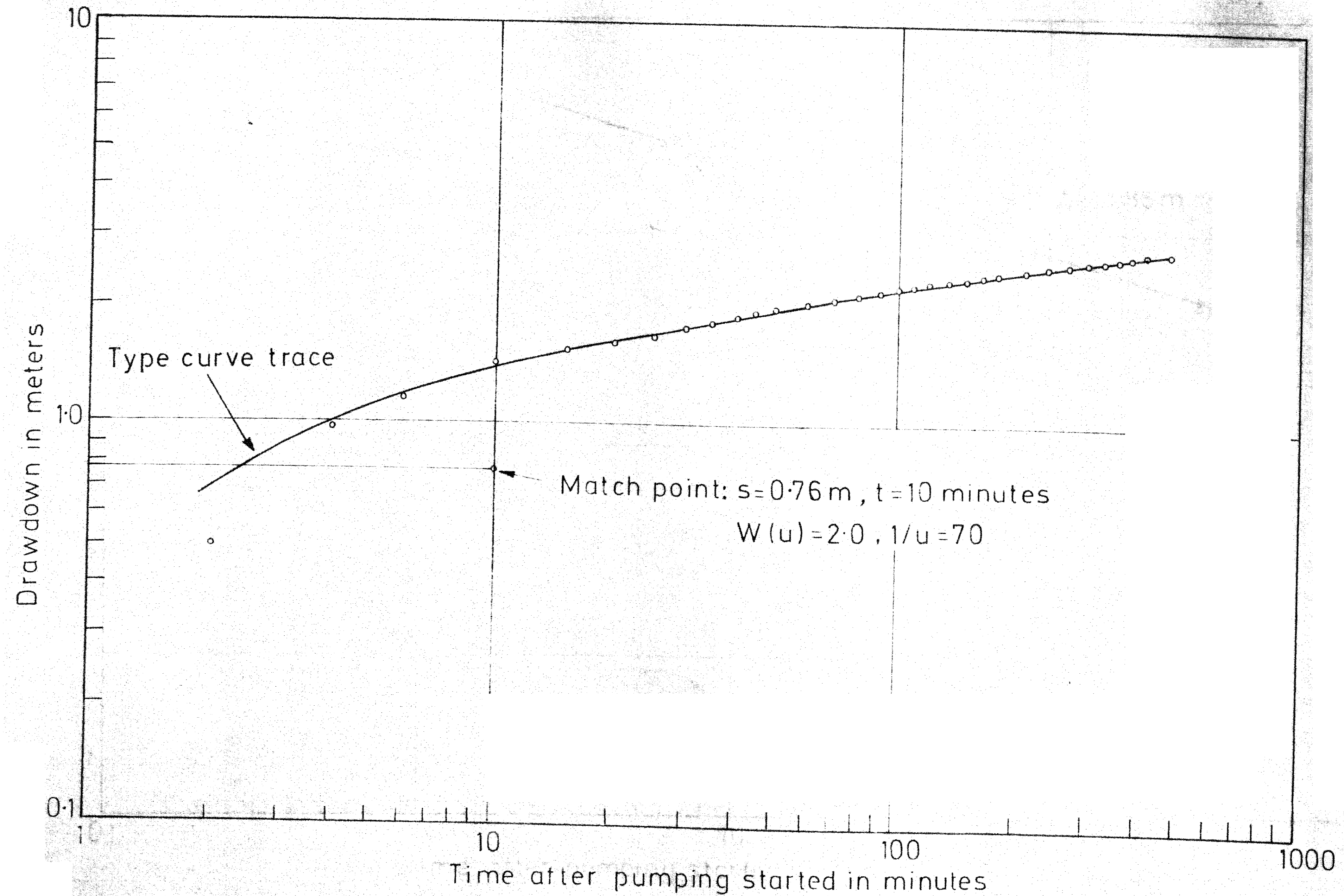


FIG.12 TYPE CURVE SOLUTION FOR OBSERVATION WELL 100FT FROM DEEP TUBE WELL NO.1 (8 hrs test)

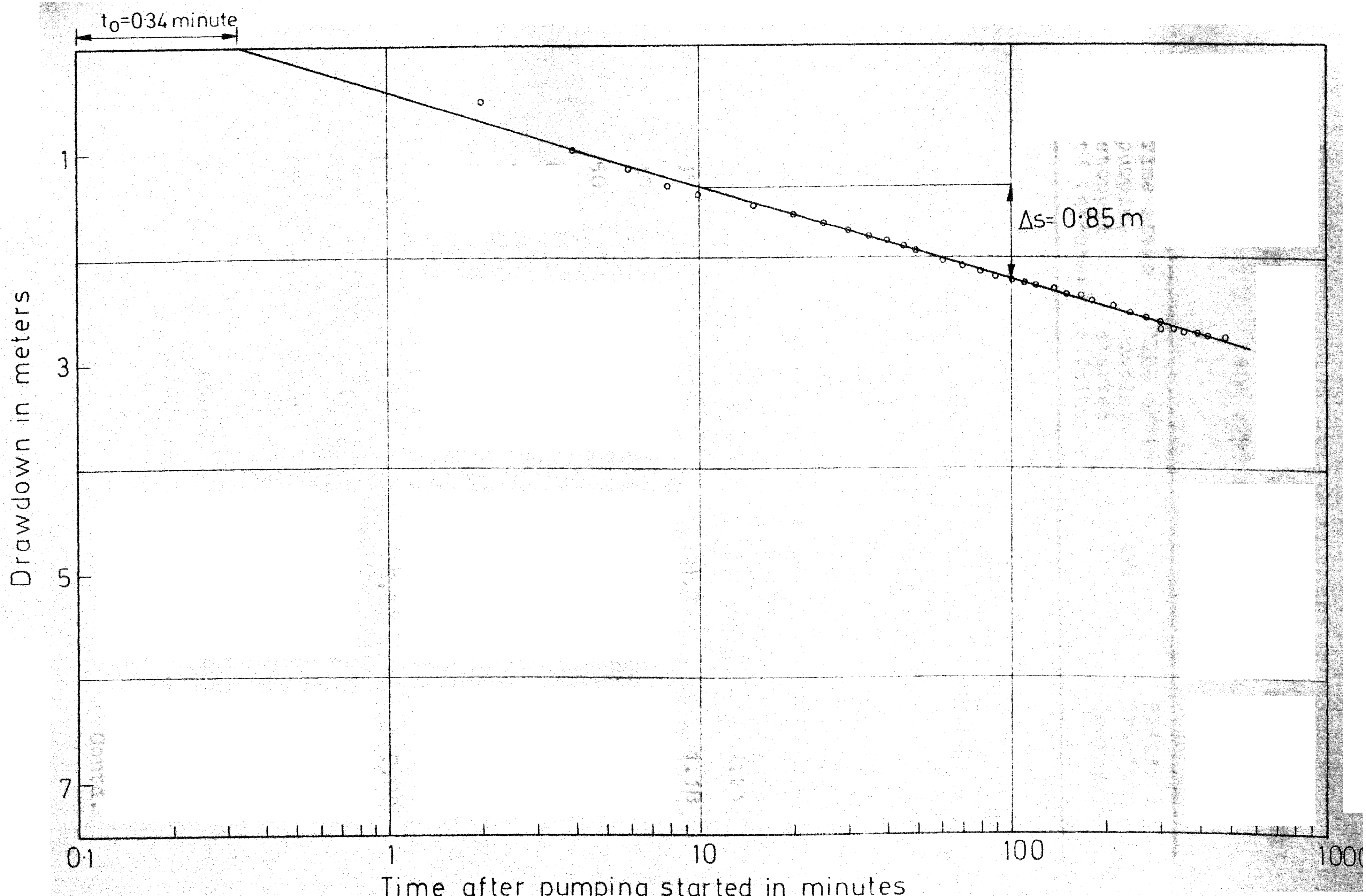


FIG.13 TIME DRAWDOWN GRAPH (8HRS TEST) FOR OBS. WELL 100 FT FROM DEEP TUBE WELL NO.1 (JACOB'S METHOD)

TABLE 16

RECOVERY TEST (AFTER 8 HRS OF PUMPING) FOR OBS WELL 100 FEET DEEP TUBEWELL No. 1

Time after pumping stopped t' (minutes)	Time after pumping started t (minutes)	t/t'	Residual drawdown (meters)
4	484	121	2.35
8	488	61	1.97
10	490	49	1.72
15	495	33	1.50
20	500	25	1.34
25	505	20.2	1.28
30	510	17	1.23
35	515	14.7	1.18
40	520	13.0	1.13
50	530	10.6	1.06
60	540	9.0	1.00
70	550	7.[illegible]	0.95
80	560	7.0	0.90
90	570	6.33	0.86
105	585	5.57	0.80
120	600	5.00	0.75
135	615	4.50	0.70
150	630	4.20	0.66
180	660	3.66	0.58
210	690	3.28	0.51

Contd.

Contd. Table 16

Time after pumping stopped t'(minutes)	Time after pumping started t (minutes)	t/t'	Residual drawdown
240	720	3.00	0.46
300	780	2.6	0.41
360	840	2.33	0.35
420	900	2.14	0.28
480	960	2.00	0.23
840	1320	1.57	0.04
960	1440	1.50	0.03
1020	1500	1.47	0.02
1080	1560	1.44	0.02

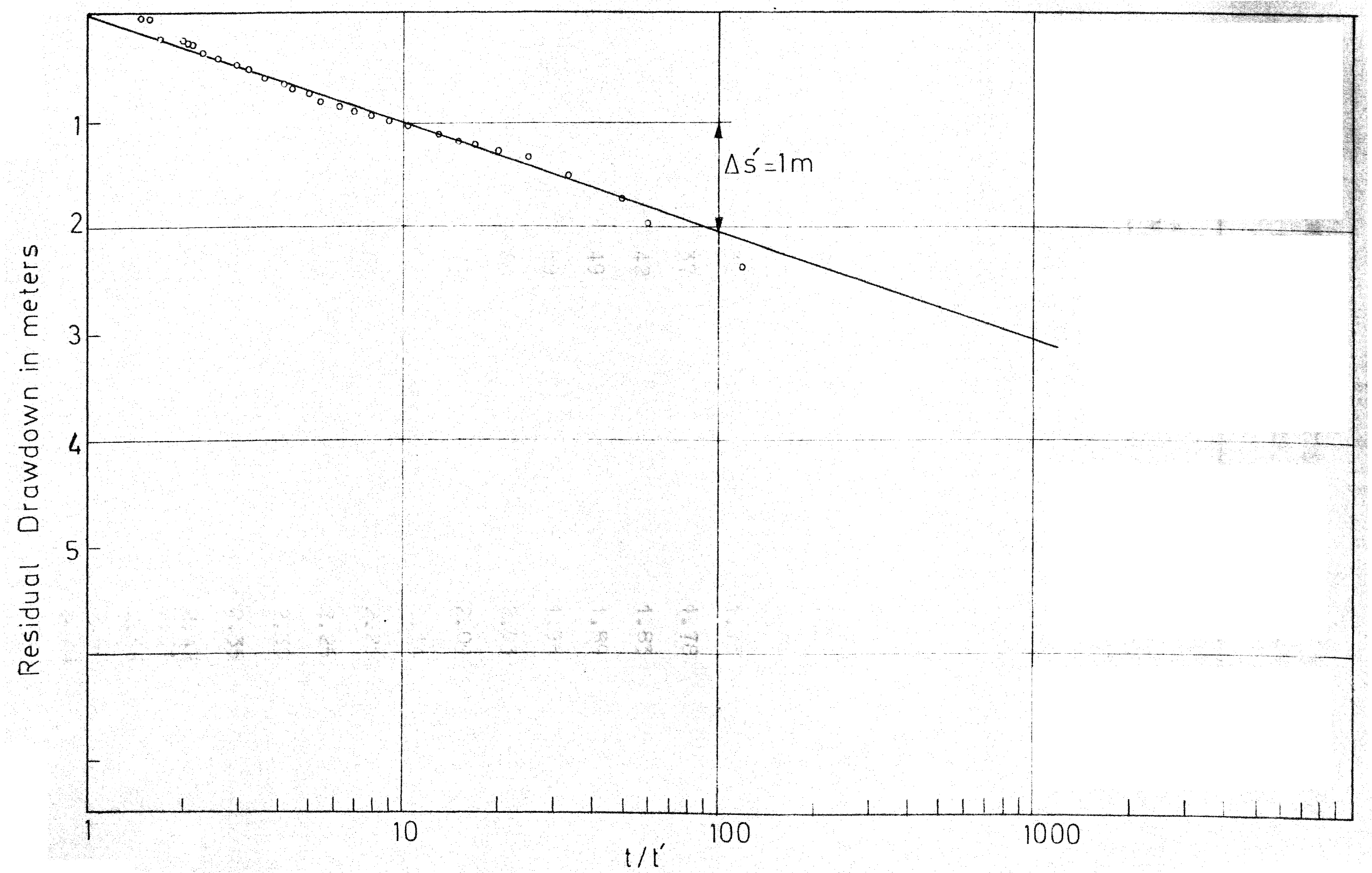


FIG. 14 RECOVERY TEST , DEEP TUBE WELL NO.1 (FOR OBS WELL)
(8 hrs test)

TABLE 17

TIME DRAWDOWN DATA FOR OBSERVATION WELL 100 FT. FROM DEEP TUBEWELL NO. 1 (6hrs. duration)

Time After pumping started (Minutes)	Drawdown (meters)
2	0.48
4	0.96
6	1.15
8	1.31
12	1.40
17	1.50
22	1.59
27	1.66
32	1.73
37	1.78
42	1.83
49	1.89
59	1.96
69	2.03
79	2.09
89	2.14
104	2.21
119	2.26
134	2.30
149	2.35
174	2.42
211	2.51
239	2.56
269	2.60
299	2.63
329	2.66
359	2.71

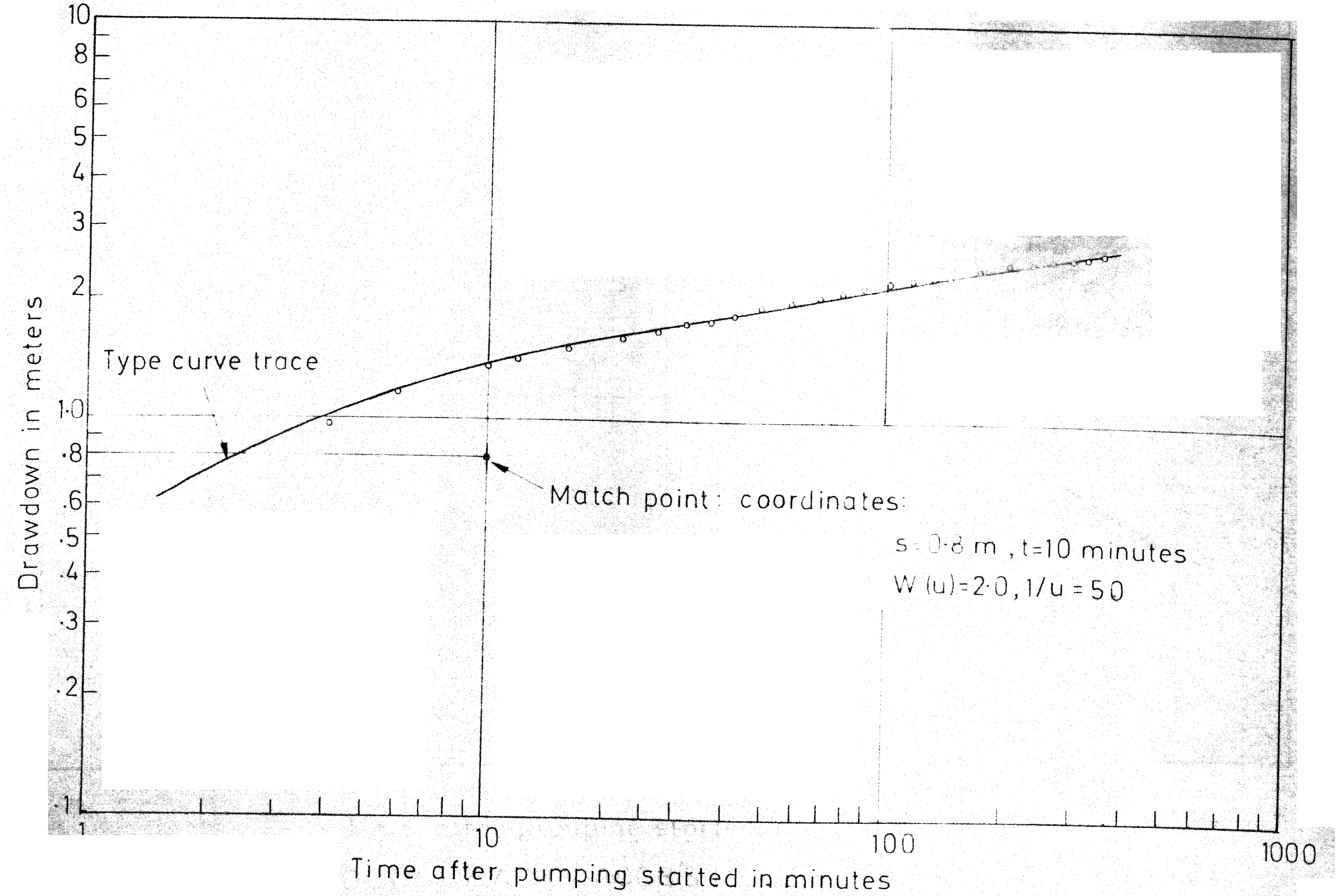
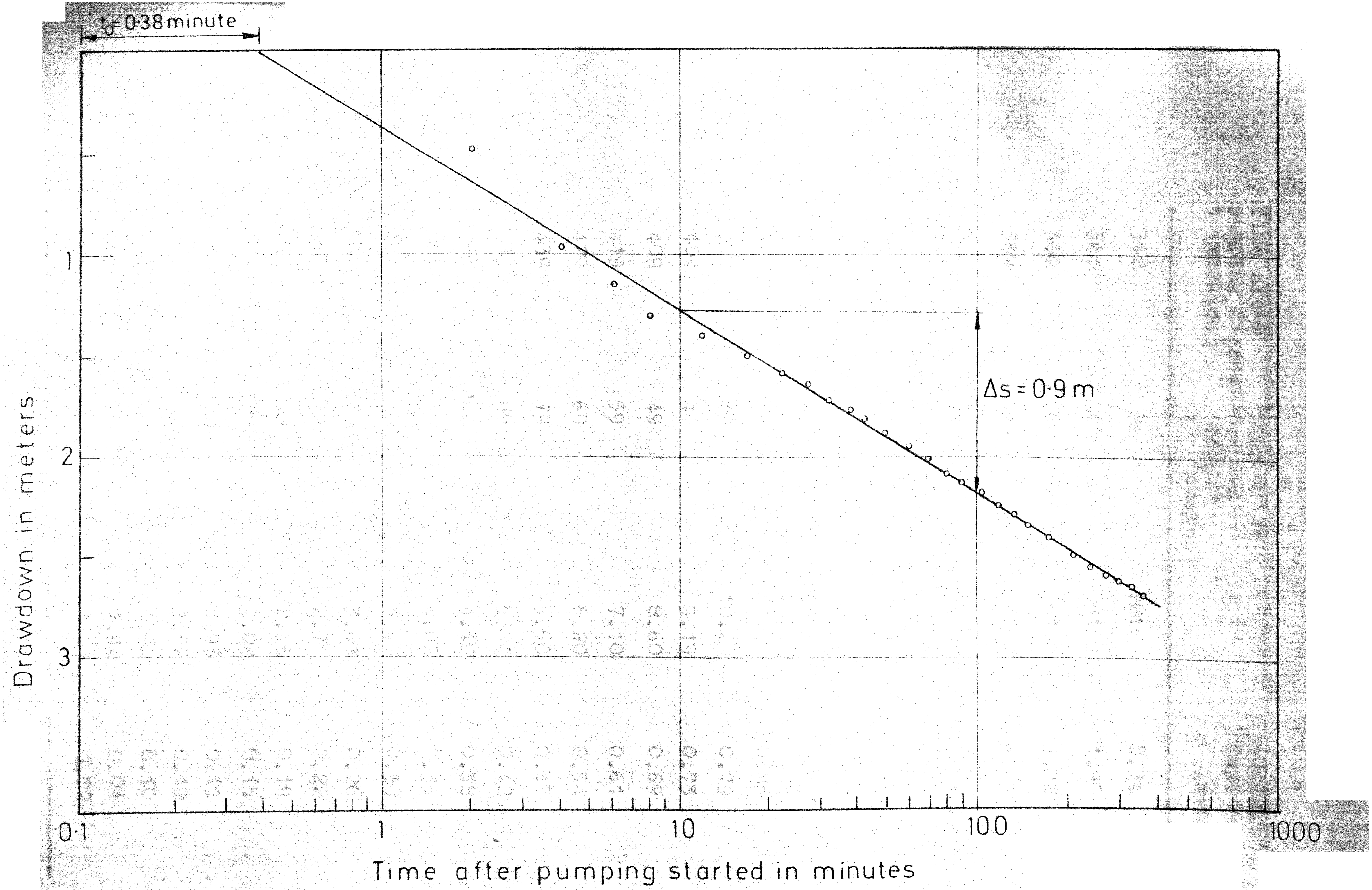


FIG.15 TYPE CURVE SOLUTION FOR OBSERVATION WELL 100FT FROM DEEP TUBE-WELL NO.1 (6hrs test)



FIG·16 TIME DRAWDOWN GRAPH (JACOB'S METHOD) FOR OBS WELL 100′ FROM DEEP TUBE WELL NO·1 (6 hrs test)

TABLE 18

RECOVERY TEST FOR OBSERVATION WELL 100 FT. FROM DEEP TUBE WELL NO. 1

Time after pumping started t (minutes)	Time after pumping stopped t' (minutes)	t/t'	Residual Drawdown s (meters)
362	2	181	2.34
364	4	91	1.97
366	6	61	1.72
369	9	41	1.49
372	12	31	1.34
374	14	26.7	1.25
379	19	19.95	1.12
384	24	16	1.01
389	29	13.4	0.92
394	34	11.6	0.85
399	39	10.2	0.79
404	44	9.19	0.73
409	49	8.60	0.69
419	59	7.10	0.61
429	69	6.20	0.54
439	79	5.50	0.47
449	89	5.04	0.42
464	104	4.40	0.38
479	119	4.02	0.35
509	149	3.40	0.30
539	179	3.01	0.26
569	209	2.7	0.22
629	269	2.35	0.19
689	329	2.09	0.15
749	389	1.93	0.13
809	449	1.82	0.12
869	509	1.70	0.10
1229	869	1.42	0.04
1409	1049	1.33	0.02

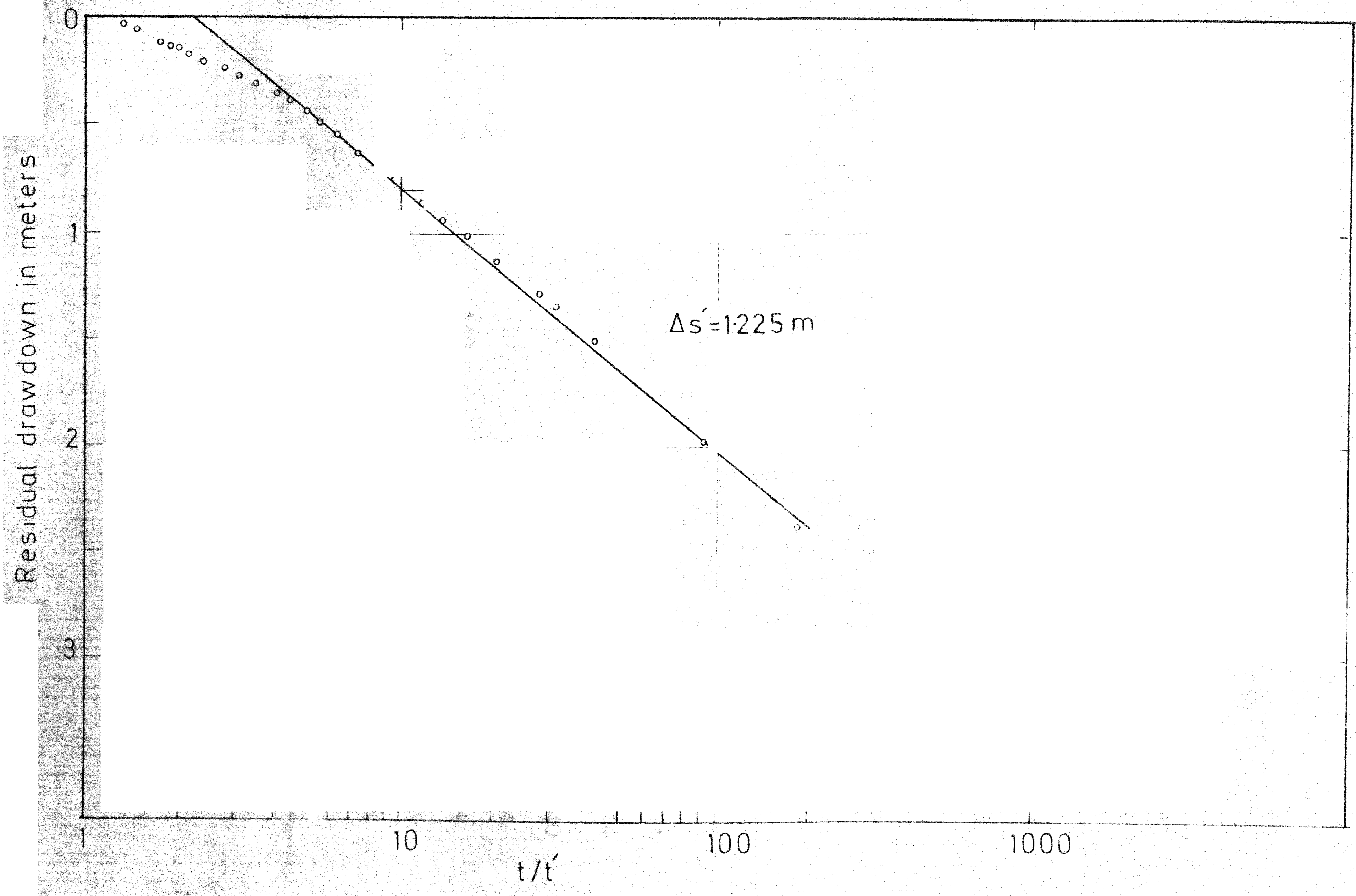


FIG.17 RECOVERY TEST, FOR OBS WELL NEAR DEEP TUBE WELL NO.1
(6 hrs test)

TABLE 19

TIME DRAWDOWN DATA FOR DEEP TUBEWELL NO.1 (STEP TEST)

Step No.	Time since pumping started (minutes)	Drawdown (ft.)	Discharge (cusecs)
I	5	7.00	0.53
	10	7.00	0.53
	15	7 50	0.53
	30	7.50	0.53
	60	7.50	0.53
II	65	12.00	0.714
	70	12.00	0.714
	75	12.50	0.714
	90	12.50	0.714
	120	12.50	0.714
III	125	17.00	0.940
	130	17.00	0.94
	140	17.50	0.94
	150	17.50	0.94
	180	17.50	0.94

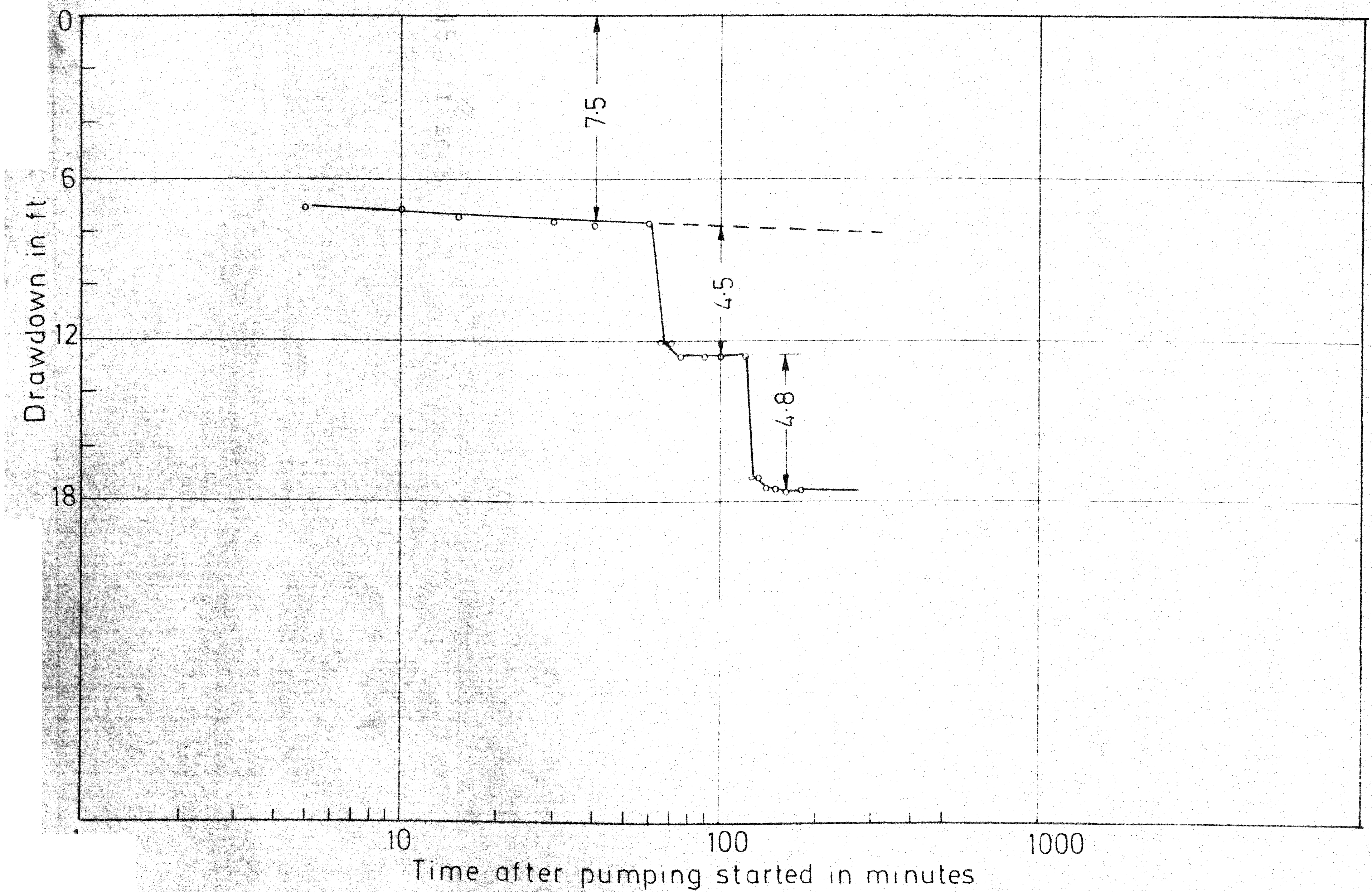


FIG 18 TIME DRAWDOWN GRAPH FOR STEP TEST, DEEP TUBE WELL NO.1

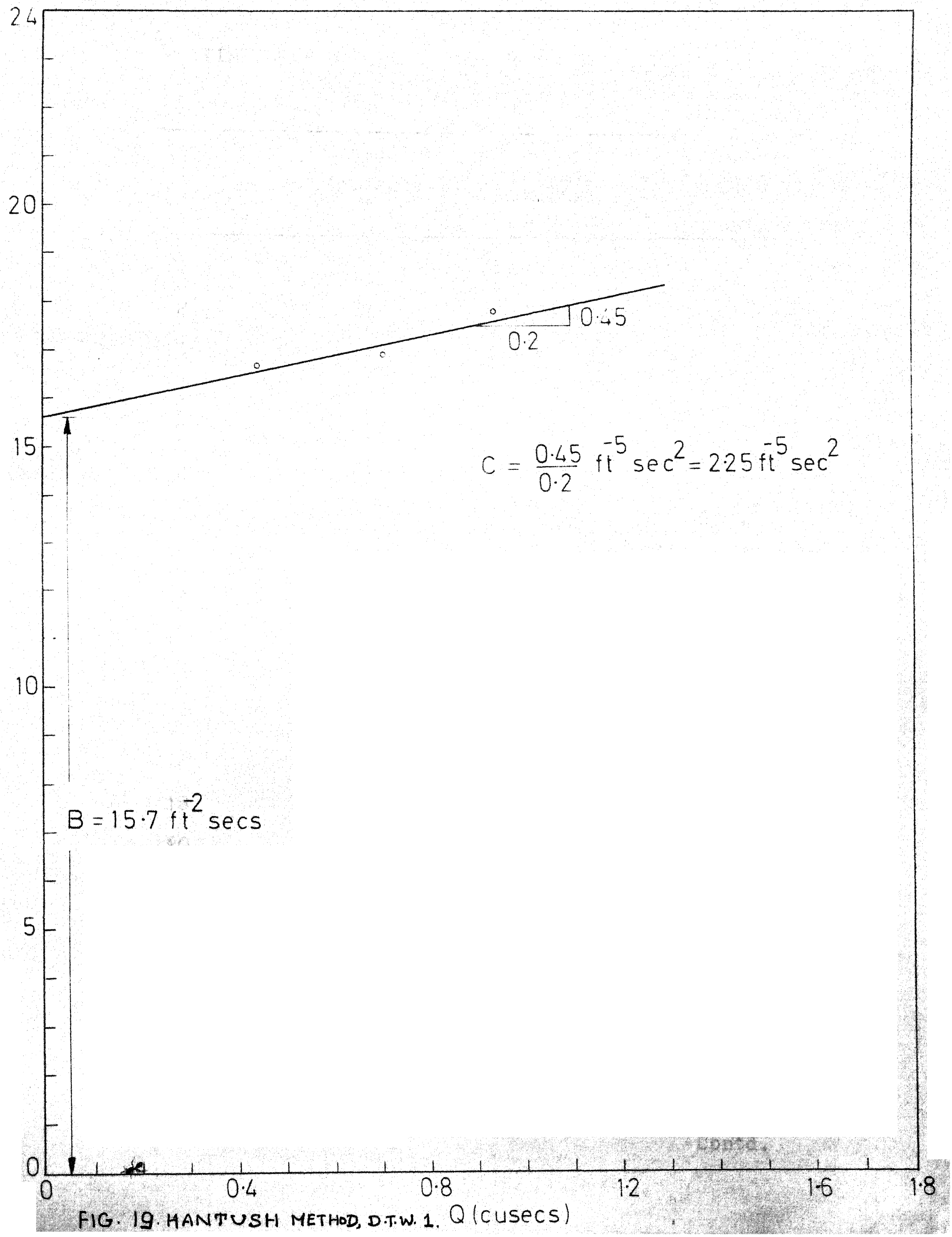


FIG. 19. HANTUSH METHOD, D.T.W. 1.

TABLE 20

TIME DRAWDOWN DATA FOR DEEP TUBE WELL NO. 2

Time after pumping started (minutes)	Drawdown (meters)	Time after pumping started (minutes)	Drawdown (meters)
1	5.52	40	5.90
2	5.57	45	6.10
3	5.70	50	5.96
4	5.66	55	5.93
5	5.82	60	5.95
6	5.53	70	6.03
7	5.61	80	6.04
8	5.70	90	6.06
9	5.69	100	6.05
10	5.65	110	6.15
12	5.65	120	6.13
14	5.75	135	6.21
16	5.80	150	6.11
18	5.82	165	6.14
20	5.90	180	6.13
22	5.80	195	6.15
24	5.93	210	6.14
26	5.90	225	6.21
28	5.91	240	6.09
30	5.88	270	6.09
35	5.90	300	6.11

Contd.

Time after pumping started (minutes)	Draw down (meters)
330	6.18
360	6.19
390	6.30
420	6.28
480	6.23
540	6.33
600	6.24
660	6.24
720	6.28
780	6.28
840	6.18
960	6.33
1080	6.28
1200	6.32
1320	6.46
1440	6.46

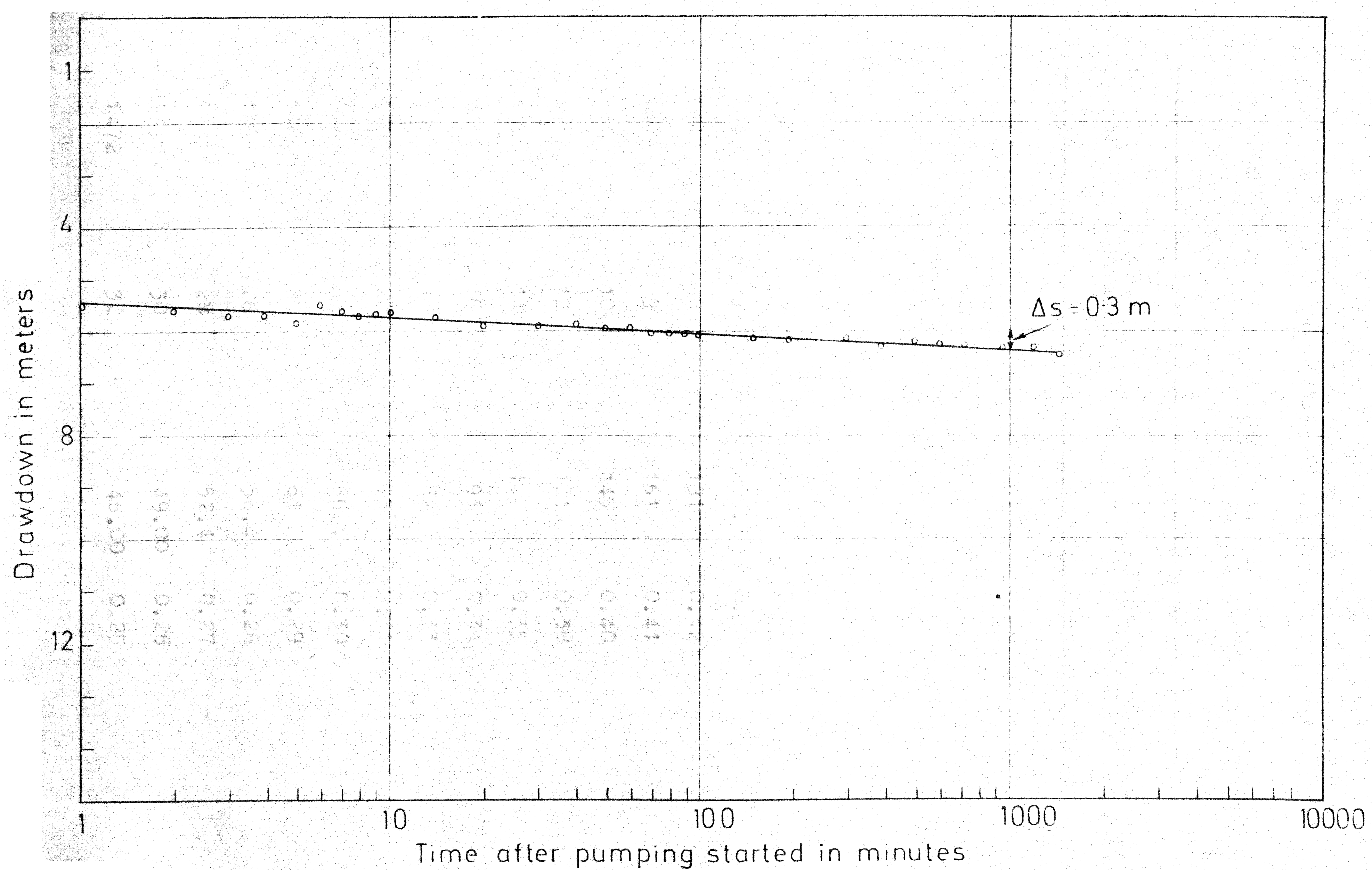


FIG 20 TIME DRAWDOWN GRAPH FOR DEEP TUBE WELL NO 2 (JACOB'S METHOD)

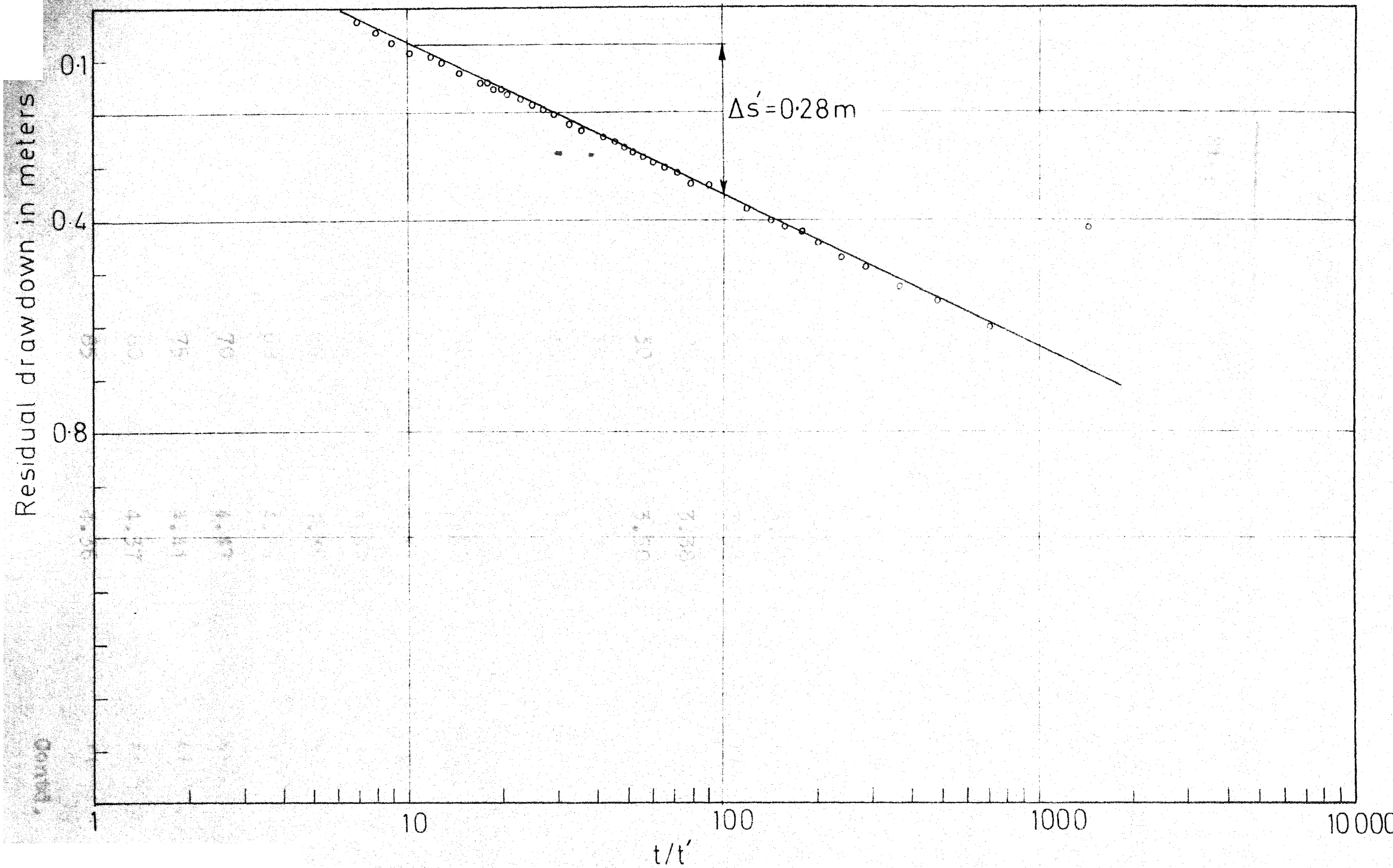
TABLE 21

RECOVERY TEST DATA FOR DEEP TUBE WELL NO. 2

Time since pumping started t (minutes)	Time since pumping stopped t' (minutes)	t/t'	Drawdown
1441	1	1441	0.41
1442	2	721	0.60
1443	3	481	0.55
1444	4	361	0.52
1445	5	289	0.49
1446	6	241	0.47
1447	7	206.7	0.44
1448	8	181	0.42
1449	9	161	0.41
1450	10	145	0.40
1452	12	121	0.38
1454	14	104	0.35
1456	16	91	0.34
1458	18	81	0.33
1460	20	73	0.31
1462	22	66.4	0.30
1464	24	61	0.29
1466	26	56.4	0.28
1468	28	52.4	0.27
1470	30	49.00	0.26
1472	32	46.00	0.25

Contd. Table 21

Time since pumping started t (minutes)	Time since pumping stopped t' (minutes)	t/t'	Draw-down
1474	34	43.3	0.25
1476	36	41.00	0.24
1478	38	39.00	0.24
1480	40	37.00	
1485	45	33	0.22
1490	50	29.8	0.20
1495	55	27.4	0.19
1500	60	25.0	0.18
1505	65	23.1	0.17
1510	70	21.6	0.16
1515	75	20.2	0.15
1520	80	19	0.15
1525	85	18	0.14
1530	90	17	0.14
1545	105	14.7	0.12
1560	120	13.00	0.10
1575	135	11.80	0.09
1590	150	10.60	0.08
1620	180	9.0	0.06
1650	210	7.8	0.04
1680	240	7.0	0.02



FIG·21 RECOVERY TEST, DEEP TUBE WELL NO. 2

TABLE 22

TIME DRAWDOWN DATA FOR DEEP TUBEWELL NO. 2 (STEP TEST)

Step No.	Time since pumping started (minutes)	Drawdown (meters)	Discharge (cusecs)
I	1	3.23	1.11
	3	3.31	1.11
	5	3.28	''
	7	3.30	''
	9	3.34	''
	11	3.23	''
	13	3.50	''
	15	3.30	''
	20	3.31	''
	25	3.38	''
	30	3.50	''
	35	3.39	''
	40	3.38	''
	50	3.50	''
	60	3.51	''
II	62	4.31	1.30
	64	4.32	''
	66	4.35	''
	68	4.45	''
	70	4.47	''
	75	4.41	''
	80	4.37	''
	85	4.36	''

Contd.

Contd. Table 22

Time since Step No.	Time since pumping started (minutes)	Drawdown (meters)	Discharge (cusecs)
II	90	4.42	1.30
	100	4.36	''
	110	4.40	''
	120	4.38	''
III	122	5.21	1.49
	124	5.13	1.49
	126	5.29	''
	128	5.18	''
	130	5.19	''
	135	5.28	''
	140	5.29	''
	145	5.36	''
	150	5.23	''
	160	5.25	''
	170	5.19	''
	180	5.30	''
IV	182	6.10	1.68
	184	6.18	''
	186	6.09	''
	188	6.33	''
	190	6.12	''
	195	6.23	''
	200	6.07	''

Contd. Table 22

Step No.	Time since pumping started (minutes)	Drawdown (meters)	Discharge (cusecs)
IV	205	6.24	1.68
	210	6.22	''
	220	6.26	''
	230	6.23	''
	240	6.31	''
V	242	6.93	1.8
	244	6.86	''
	246	6.87	''
	248	6.82	''
	250	6.86	''
	255	6.78	''
	260	6.92	''
	265	6.81	''
	270	6.79	''
	280	6.90	''
	290	6.91	''
	300	6.82	''

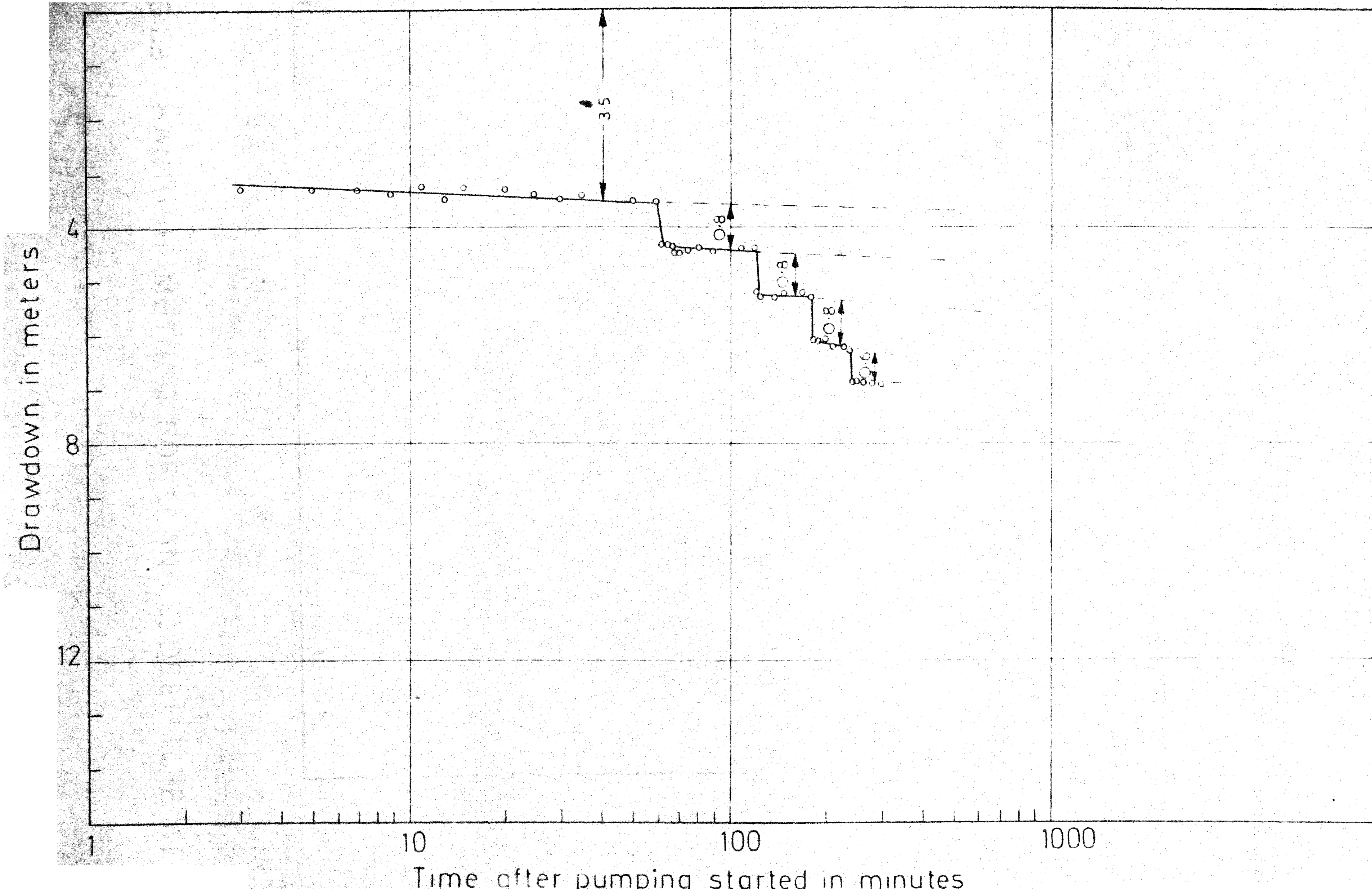


FIG.22 STEP TEST, DEEP TUBE WELL NO 2

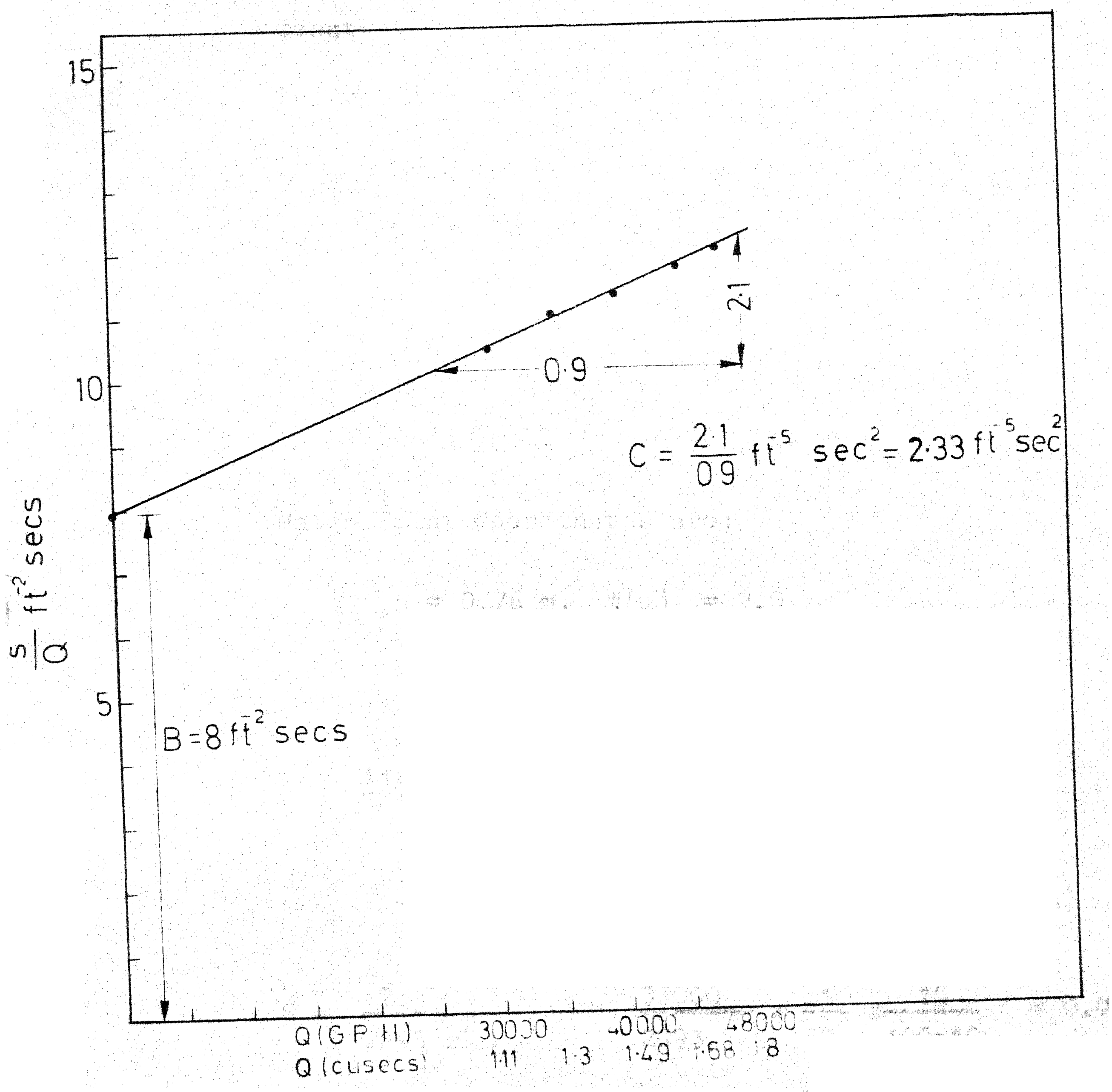


FIG.23 · HANTUSH METHOD FOR B AND C, DEEP TUBE WELL NO.2

3.2 Results of Pumping Tests:

Deep Tube Well No.1 (8 hrs. Test)

Constant discharge test:

i) Type curve method (Fig. 12)

Head measured over the 90° V notch = 8''

$$\text{Discharge } Q = 2.56\ H^{5/2} = 2.56\ (8/12)^{5/2} \text{ cusec}$$

$$= 0.94 \text{ cusec } (350 \text{ gpm})$$

Distance from the pumping well to observation well = r = 100 ft.

Match Point Coordinates are:

$$s = 0.76 \text{ m}, \quad W(u) = 2.0$$

$$t = 10 \text{ minutes}; \ \frac{1}{u} = 70$$

$$T = \frac{114.6\ Q\ W(u)}{s} = \frac{114.6 \times 350 \times 2}{0.76 \times 3.28} \text{ gpd/ft.}$$

$$= 32000 \text{ gpd/ft. } (476800 \text{ lpd/m})$$

$$S = \frac{Tut}{2693\ r^2} = \frac{32000}{2693} \times \frac{1}{70} \times \frac{10}{100 \times 100} = 0.00017$$

ii) Jacob's Method:

Δs from graph (Fig. 13) = 0.85 m

$$T = \frac{2.3\ Q}{4\pi\ \Delta s} = \frac{2.3 \times 0.94}{4 \times 3.14 \times 0.85 \times 3.28}\ ft^2/sec.$$

$$= 0.06\ ft^2/sec. = 32600\ gpd/ft.$$

(485000 lpd/m)

t_o (Fig. 13) = 0.34 minute = 22.4 seconds.

$$S = \frac{2.25\ T\ t_o}{r^2} = \frac{2.25 \times 0.06 \times 22.4}{100 \times 100}$$

$$= 0.00027$$

<u>Recovery Test:</u>

$\Delta s'$ from graph (Fig. 14) = 1 m (3.28 ft.)

$$T = \frac{2.3\ Q}{4\pi\ \Delta s'} = \frac{2.3 \times 0.94}{4 \times 3.14 \times 3.28}\ ft^2/sec = 0.051\ ft^2/sec.$$

$$= 27500\ gpd/ft\ (409000\ lpd/m)$$

$$T_{av} = \frac{32600 + 27500}{2}\ gpd/ft = 30050\ gpd/ft.$$

(447000 lpd/m) ; b = 123.85 m = 412.80 ft.

$$K_{av} = \frac{T_{av}}{b} = \frac{30050}{412.8}\ gpd/ft^2 = 73\ gpd/ft^2\ (3600\ lpd/m^2)$$

6 Hours Test:

i) Type curve solution (Fig. 15)

$Q = 0.94$ cusec (350 gpm)

$r = 100$ ft.

Match point coordinates:

$s = 0.8\,m$; $W(u) = 2.00$

$t = 10$ minutes; $1/u = 50$

$$T = \frac{114.6\ Q\ W(u)}{s} \quad \frac{114.6 \times 350 \times 2}{0.8 \times 3.28} \text{ gpd/ft.}$$

$$= 30550 \text{ gpd/ft} \quad (455000 \text{ lpd/m})$$

$$S = \frac{Tut}{2693\ r^2} = \frac{30550}{2693} \times \frac{1}{50} \times \frac{10}{100 \times 100}$$

$$= 0.00023$$

ii) Jacob's Method:

Δs (from Fig. 16) = 0.9 m

$Q = 350$ gpm (0.94 cusec)

$$T = \frac{2.3\ Q}{4\pi\ \Delta s} \quad \frac{2.3 \times 0.94}{4 \times 3.14 \times 0.9 \times 3.28} \text{ ft}^2\text{/sec.}$$

$$= 0.057 \text{ ft}^2\text{/sec.}$$

$$= 30600 \text{ gpd/ft} \quad (456000 \text{ lpd/m})$$

t_o (Fig. 16) = 0.38 minute = 22.8 secs.

$$S = \frac{2.25\ T\ t_o}{r^2} = \frac{2.25 \times 0.057 \times 22.8}{100 \times 100}$$

$$= 0.00029$$

Recovery test (Fig. 17)

$\Delta s' = 1.225$ m

$$T = \frac{2.3Q}{4\pi\Delta s'} = \frac{2.3 \times 0.94}{4 \times 3.14 \times 1.225 \times 3.28}$$

$= 0.043\ ft^2$/sec. (23000 gpd/ft.)

342800 lpd/m.

Step-drawdown Test:

Table 23

Hantush Method (Fig. 18 and 19)

Step No.	Q (cusecs)	s(ft.)	s/Q
1	0.45	7.5	16.67
2	0.71	12.0	16.90
3	0.94	16.8	17.80

From graph (Fig. 19), $B = 15.8\ ft^{-2}$ secs ($172\ m^{-2}\ sec^2$)

$C = 2.25\ ft^{-5}\ sec^2$ ($854\ m^{-5}\ sec^2$)

Table 24

Walton's Method

Step No.	Δs(ft.)	ΔQ (cusec)	$\frac{\Delta s}{\Delta Q}$
1	7.5	0.45	16.67
2	4.5	0.26	17.30
3	4.8	0.23	20.90

$$C_{12} = \left(\frac{\Delta s_2}{\Delta Q_2} - \frac{\Delta s_1}{\Delta Q_1}\right) / (\Delta Q_1 + \Delta Q_2) = \frac{17.3 - 16.67}{0.71}$$

$$= 0.9 \text{ ft}^{-5} \text{ sec}^2 \quad (342 \text{ m}^{-5} \text{ sec}^2)$$

$$C_{23} = \left(\frac{\Delta s_3}{\Delta Q_3} - \frac{\Delta s_2}{\Delta Q_2}\right) / (\Delta Q_2 + \Delta Q_3) = \frac{20.9 - 17.3}{0.49} \text{ ft}^{-5} \text{ sec}^2$$

$$= 7.3 \text{ ft}^{-5} \text{ sec}^2 \quad (2774 \text{ ft}^{-5} \text{ sec}^2)$$

Deep Tube Well No. 2

Constant Discharge Test:

Δs from Fig. 20 = 0.3 m (1 ft.)

Q = 42000 us. gallons per hour or 700 us. gpm

= 1.55 cusecs.

$$T = \frac{2.3\ Q}{4\pi\ \Delta s} = \frac{2.3 \times 1.55}{4 \times 3.14 \times 1}\ ft^2/sec.$$

$$= 0.284\ ft^2/sec.$$

$$= 153000\ gpd/ft\quad (2285000\ lpd/m)$$

Recovery Test (Fig. 21)

$\Delta s'$ from graph = 0.28 m

$$T = \frac{2.3\ Q}{4\pi\ \Delta s'} = \frac{2.3 \times 1.55}{4 \times 3.14 \times 0.28 \times 3.28}\ ft^2/sec.$$

$$= 0.3\ ft^2/sec.$$

$$= 161600\ gpd/ft.\quad (2408000\ lpd/m)$$

$$T_{av} = \frac{153000 + 161600}{2}\ gpd/ft$$

$$= 1.57,300\ gpd/ft\quad ,\quad b = 42.3\ m\ (140\ ft.)$$

(2346500 lpd/m)

$$K_{av} = \frac{T_{av}}{b} = \frac{1,57,300}{140}\ gpd/ft^2\quad (55000\ lpd/m^2)$$

$$= 1123.57\ gpd/ft^2$$

Continued

Table 25

Hantush Method (Fig. 22 and 23)

Step No.	Discharge Q cusec	Drawdown (s) ft.	s/Q
1	1.11	3.5 m (11.6)	10.43
2	1.30	4.3 m (14.2)	10.92
3	1.49	5.1 m (17.0)	11.40
4	1.68	5.9 m (19.7)	11.70
5	1.80	6.5 m (21.6)	12.00

From graph (Fig. 23) B = 8 ft.^{2} secs (87 m^{-5} secs)

C = 2.33 ft^{-5} sec^2 (880 m^{-5}sec^2)

Table 26

WALTON'S METHOD

Step No.	ΔQ (cusecs)	Δs (ft.)	$\Delta s/\Delta Q$
1	1.11	3.5 m (11.6')	10.43
2	0.19	0.8 m (2.6')	13.70
3	0.19	0.8 m (2.6')	13.70
4	0.19	0.8 m (2.6')	13.70
5	0.12	0.6 m (2')	16.67

$$C_{12} = \frac{13.70 - 10.43}{1.11 + 0.19} \text{ ft}^{-5} \text{ sec}^2 = 2.51 \text{ ft}^{-5} \text{ sec}^2$$
$$(950 \text{ m}^{-5} \text{ sec}^2)$$

$$C_{23} = C_{34} = 0; \quad C_{45} = \frac{16.67 - 13.70}{0.19 + 0.12}$$

$$= 9.5 \text{ ft}^{-5} \text{ sec}^2 \quad (3610 \text{ m}^{-5} \text{ sec}^2)$$

3.3 Chemical Quality of Water from Deep Tube Wells:

In the table the chemical characteristics of water from three deep tube wells have been presented.

Table 27

Chemical Analyses of Water from Deep Tube Wells

Tube Well LOCATION	pH	Sp. Conductivity micromhos	T.D.S. mg/l	Alkalinity mg/l	Hardness mg/l	Cl mg/l	Sulphate mg/l
IIT(D.T.W.1)	7.9	5740	3750	170	974	700	880
IIT(D.T.W.2)	7.6	1890	1230	220	144	550	82
Limbs Factory	8.1	870	580	304	150	48	nil

It is interesting to note that the water from the deep tube well No. 1 is saline in its character and in particular the total dissolved solids content and sulphate content are far too above the recommended levels for drinking

water supply. Hence it is recommended that this well is not to cater for drinking water supply.

Since the deep tube well No. 2 is tapping only aquifers beyond 318 m depth, the chemical analysis for that well water precisely reflects the quality of water from deep aquifers. Thus a comparison with a shallow well in its immediate neighbourhood brings out the basic differences in the water quality of shallow and deep aquifers. The total dissolved salt content in waters from deep aquifers (1230 mg/l) is at least 5 times that for waters from shallow aquifers (214 mg/l) and the chloride content is at least ten times that for water from shallow wells. It has also been observed that the temperature of water in deep tube well No. 2 is around 35.5° C compared to that of water from tube well No. 5 which is around 29.5° C, measurement carried out on the same day around the same time. The air temperature at this time was 38°C.

The effect of connecting deep tube well No. 2 to the main pipe network is indicated in the following report of chemical analysis of samples taken from different consumer ends of the campus.

Table 28

Chemical Analysis of Water Samples from Various consumer Points

Location and date	Sp. conductivity micro mhos	T.D.S. mg/l	Total hardness mg/l of Cal CO_3
Type IV area 21.5.74	1.47×10^3	936	184
Academic Area 21.5.74	1.44×10^3	910	184
Hostel Area 21.5.74	1.26×10^3	810	192
Type II 21.5.74	1.47×10^3	936	188
Type VI Area 22.5.74	1.68×10^3	1090	174
Type IA Area	1.09×10^3	705	184

From the above figures it can be seen that after mixing the water of deep tube well No.2 with that of shallow wells the T.D.S. is brought well within the safe limit except in the type VI area where the T.D.S. is slightly more as it is closer to the deep tube well No. 2. T.D.S. in type I A area is the least as expected.

CHAPTER 4

DISCUSSION ON RESULTS

4.0 After having dealt with the characteristics of shallow and deep aquifers, a comparison of both can be made. Table 29 indicates the same. Since four tube wells (two of each type) have been tested during the present study, the results in the table contain data from these wells.

Table 29

Comparison of Characteristics of Shallow and Deep Aquifers

Particulars	Shallow Tube Wells		Deep Tube Wells	
	No. 3	No.5	No.1	No.2
Deth in meters (ft)	120 (400)	111 (370)	416 (1368)	399.63 (1312)
Casing dia in cms (inches)	15 (6)	15 (6)	15 (6)	20.00 (8)
Thickness of aquifer tapped in meters (ft.)	18 (60)	21 (70)	123.85 (412.8)	42.3 (140)
Nature of Strata	Medium to coarse grained sand	Medium to coarse grained sand	Medium to coarse grained sand (silty)	Gravel
Discharge in lpm (gpm)	1125 (250)	900 (200)	1575 (350)	2613 (583)

Contd.

Contd. Table 29

Particulars	Shallow Tube Wells No. 3	Shallow Tube Wells No. 5	Deep Tube Wells No. 1	Deep Tube Wells No. 2
Draw down in meters (after 8 hrs. of pumping) (ft)	5.7 (19)	5.7 (19)	6.45 (21.50)	6.25 (20.75)
Specific Capacity in lpm/m (gpm/ft.)	196 (13.16)	168 (10.52)	241 (16.3)	416 (28.1)
Transmistibility in lpd/m (gpd/ft.)	387500 (26065)	305250 (20500)	447000 (30050)	2346500 (157300)
Well loss coefficient in m^{-5} sec^2 (ft^{-5} sec^2)	2784 (7.33)	3585 (9.44)	854 (2.25)	880 (2.33)
Formation loss coefficient in m^{-2} sec. (ft^{-2} sec)	190 (17.6)	238 (22)	172 (15.6)	87 (8)

From the above figures it can be seen that aquifers tapped by deep tube well No. 2 have the best characteristics like high transmissibility, high specific capacity and low well loss coefficient. Though it is stated in general that deep aquifers are more productive than shallow ones aquifers tapped by deep tube well No. 1 seem to be an exception. Though the thickness tapped is maximum, the transmissibility is poor which indicates low permeability. The specific capacity of

this tube well is not very high compared to the shallow ones whereas deep tube well No. 2 has specific capacity more than twice that of shallow wells.

Out of the shallow tube wells tube well No. 3 has the best performance which is possibly due to the maximum thickness of the productive aquifer (third system) tapped by this well.

It is to be noted that the above tube wells tap more than one aquifer which requires the application of the analysis of multi-layer aquifers. But even in the case of a two layered aquifer the solution is quite complicated and requires observation wells tapping individual aquifers. Hence such an analysis could not be used. The standard methods for ideal aquifers which are used in the analysis give the characteristics of an equivalent aquifer (single layer) having the thickness equal to the sum of the thicknesses of the aquifers tapped and help us to understand the overall nature of the multilayered aquifers.

4.1 From the figures given below it is seen that there is marked difference between shallow and deep aquifers in chemical quality of water. The water from deep aquifers is characterised by high T.D.S. and chloride contents as compared to that from shallow ones.

Table 30

Comparison of Chemical Characteristics of Water of Shallow and Deep Aquifers

Chemical Characteristics	Tube well No. 1	No. 3	No. 4	No.5	D.T.W. No.1	D.T.W No.2
Hardness (mg/l)	150	170	205	210	974	144
Chloride (mg/l)	10	44	45	53	700	550
Total dissolved Solids (mg/l)	201	175	202	214	3750	1230
Sulphates (mg/l)	n.d	n.d.	n.d.	n.d	880	82
pH	81	7.7	8.0	7.9	7.9	7.6

n.d. - not-determined

It has been found by previous studies that the T.D.S. in ground water of Kanpur varies from 74-840 mg/l. The T.D.S. in the case of the shallow wells falls within this range, whereas in the case of the deep tube wells, it is more. In particular, the T.D.S. of water from deep tube well No. 1 is very high (more than 3 times the maximum allowable value). Water from both the deep tube wells has chloride content out side the range of

5-444 p.pm of ground water of Kanpur and this is higher than the maximum value specified for drinking. The water of deep tube well No. 1 has a very high sulphate content which is either absent or very small in other cases.

Thus even in chemical quality the deep tube well No. 1 widely departs from the general nature of deep tube wells.

4.2 Discussion on the Results of Step-drawdown Test:

The step-drawdown test has been under strong critical review during these years. It is worth while to deal in brief such reviews and then discuss the test results of present study.

Jacob's (1946) method of analysis of the step-draw down test is based on the equation $s = BQ + CQ^2$ with the usual notation. Rorabaugh (1953) suggested a modification to the above and his equation for the total drawdown is $s = BQ + CQ^n$.

In Jacob's method B and C are determined from the analysis of the data, while in Rorabaugh's method the exponent n is also to be determined in addition, to B andC. WALTON (1962) stated that Jacob's method was adequate in practice and after having conducted a number of step-drawdown tests, gave his conclusions as guide lines for

Judging the well development and efficiency by the value of C.

Lennox (1966) discussed the application of Rorabaugh's method in analysing his data and observed that Rorabaugh's method is better than Jacob's method.

Mogg (1969) however, strongly critisized WALTON'S conclusions and according to him the value of C cannot be used as an indicator of well development, degradation or well condition.. Thus Mogg suggested a modified procedure for conducting the test.

Sheahan (1972) presented his view in favour of Walton's recommendations and concluded that the step test is still one of the simplest and most useful tools available in well hydraulics.

Karnjac (1972) remarked that the step test which is the test performed on the well, alone cannot yield information regarding well acceptability. He stated that it might happen that the production in a well is much below its maximum specific capacity due to clogging or something else, and yet show a small value of C and a small value of C according to Walton would imply a properly developed well and as such the step test needs a critical review. He stated that the step test can be accepted as one of the simplest and most useful tools provided one knows what

one may expect from that. He concluded that the constant discharge test with one observation well within the cone of depression is much more useful than a step test with the pumping well alone.

As we are dealing with the ground water reservoir which exhibits wide variations in its characteristics in time and space, it is quite likely that the analysis of different sets of data lead us to different conclusions. The proper thing is to apply any particular procedure to the practical situations and compare the results of analysis with the actual conditions. If there is good correspondence between the two, the usefulness of the test is proved and if not, proper discretion should be used to find out the factors responsible for the disagreement and suggest suitable modifications in test procedure and method of analysis if necessary.

From the results of the step drawdown test presented earlier, it can be seen that WALTON'S recommendations provide a satisfactory method of judging well conditions as explained below.

For the deep tube wells No. 1 and No. 2 the values of C are $2.25\ ft^{-5}\ sec^2$ and $2.33\ ft^{-5}\ sec^2$ which according to Walton indicate properly developed wells. It may be stated that these wells were indeed developed till clear water was pumped.

The values of C for tube wells No. 3 and No. 5 are 7.33 ft^{-5} sec^{2} and 9.74 ft^{-5} sec^{2} which indicate mild determination and clogging which may be quite possible as these wells have been functioning for the last six to seven years.

Hence the step-drawdown test can be considered as a useful tool in well hydraulics.

CHAPTER 5

FUTURE PROJECTIONS AND SUGGESTED PROPOSALS

5.0 Past Performance of Shallow Tube Wells:

Before projecting the future requirements of water supply in the campus, it is essential to review the entire past performance and the goals that wer set at the time of installation of the units for the supply.

The first tube well was installed in the year 1963 and the subsequent ones were completed by about 1967-68. At that time the demands were: (As per WILKE'S report):

Domestic or institutional	- 400000 gal/day
Air Conditioning	- 432000 gal/day
Irrigation water	-2400000 gal/day

It was expected that the ultimate development of the irrigation water needs would not occur in the near future.

For drinking, institutional and air conditioning purposes a supply of 1,816,000 was expected from the tube wells (No. 1 to No. 6). Since 832000 gal/day was needed for domestic, institutional and air-conditioning purposes this supply was expected to be sufficient even with an outage of one or possibly two tube wells for repair

or maintainance. For irrigation water 1360000 gpd was expected from existing and proposed dug wells and the remaining (approx.) 1,000000 gpd was expected from the tube wells under full operating conditions.

Subsequently several factors ledto the scarcity of water supply and drop in pressure at the consumer point. This was caused by factors like maintainance problems for some tube wells and consequent abandonment of tube well No. 2 and overpumping of the other tube wells.

Table 31

Details of supply from Shallow wells at present (April 74)

Tube Well No.	Discharge (gpH)	Hours of supply (per day)
1	3000	22
3	13000	22
4	12000	22
5	10000	22

Total quantity of water supplied from shallow wells for domestic, academic and horticultural purposes = (3000 + 13000 + 12000 + 10000) x 22 gallons per day

= 8,36,000 gpd.

<u>The Present Population:</u>

No. of quarters of all types = 821

Taking an average of 6 per quarter, total no. of

residents = 821 x 6 = 4926

No. of students	=	2000
Total	=	6926

Including visitors, etc. total population can be taken as 8000.

Daily per capita consumption = $\frac{8,36,000}{8000}$ = 104.5 gallons.

(Before connecting deep tube well No. 2.)

5.1 Future Plans:

The following future plans are proposed:

1. One more hostel
2. Married students apartments
3. Students community hall
4. Aeronautical Engineering Block
5. Some more quarters of all types in addition to 71 quarters nearing completion.
6. Swimming Pool.

Keeping these things in view the future demand is to be worked out.

5.2 Future Demand and Proposals to meet it:

The population by 2001 is predicted on the basis of an assumed percentage growth. The percentage growth is assumed on the basis of the findings of the National Agricultural Commission working group. In the period 1961-71 the actual growth rate was 3.25 per cent per year. It is expected that the overall population growth rate will be

2 per cent per year during 1971-1981
1.55 per cent per year during 1981-1991
1.30 per cent per year during 1991-2001

But during 1961-71 urban population growth rate was 4.2 per cent as against the over all growth rate of 3.25 per cent. It is expected that the urban population growth rate will increase to 5 per cent by 2000 A.D.

Though the growth rate of the population of the Campus cannot be taken as 5 per cent as mentioned above as it is not an industrial or commercial area, a growth rate which is higher than the over all growth rate is to be assumed. On this basis it is reasonable to assume a frowth rate of 3 per cent per year (30 per cent per decade).

Hence the expected population by 1981 = 8000 $+ \frac{3}{100} \times 8000 \times 7$ $= 9680$

the expected population by 1991 $= 9680 + \frac{3}{100} \times 10 \times 9680$ $= 12584$

the expected population by 2001 $= 12584 + \frac{3}{100} \times 12584$ $= 16359$

Though it is not reasonable to include the student population of 2000 in the above calculation, it has been included to take care of the quantity of water required for one more hostel, swimming pool etc.

On the basis of the actual per capita consumption of 104.5 gpcd which itself is higher than the recommended per capita supply for any type of area in India, mentioned above, a per capita consumption of 110 gpcd.

can be taken for predicting future demand by 2001.

Hence the future demand by 2001

$= 16359 \times 110$ gpd $= 17,99,490$ gpd say 18,00000 gpd.

After connecting deep tube well No. 2 to the system the following is the supply position at any particular time:

Contd.

TABLE 31(a)

Details of supply after connecting D.T.W. No. 2

Tube well No.	Discharge	No. of hours of pumping	Total Supply per day
3	13000 gpH	22	5,50,000 gpd
4	12000 gpH	22	
5	10000 gpH	20	2,00000 gpd
Deep tube Well No. 2	34000 gpH	19	646000
(T.W.1 under repair)		Total	1396000 gpd

This comes to 77.6% of the projected demand and hence extra sources for making up the demand by 2001 are needed.

This does not mean that the existing shallow wells would continue to exist. They may have to be replaced after every 10 to 15 years by an equivalent kind providing similar quantities of water.

Both shallow and deep tube wells are recommended as the mixing of water from deep tube wells (yielding high discharge) with that from the shallow ones improves its quality as evidenced by the chemical analyses of samples taken from different parts of the campus after connecting deep tube well No. 2 to the system.

The shallow and deep tube wells are to be located in the Northern part of the campus area, as in the Southern part not only the third system of shallow

aquifers is missing, but the deep aquifers only provide saline water.

5.3 Pressures in the Distribution System and Proposals To Meet Pressure Requirement:

The existing distribution system consists of a net work of water mains of diameter varying from 3'' to 12''. The pressure at the source varies from 30 to 40 psi. The main line pressures as observed at various consumer points in the campus before connecting deep tube well No. 2 are given in the following table:

Table 32

Main Line Pressures at Various Consumer Points of IIT Campus
Fig. 24

Sl. No.	Location	Pressure in psi
1.	Type IV and V (near Tube Well 4 and 5)	10.5 to 13.5
2.	Type III near tube well No. 4	11.5 to 18.5
3.	Type III near gate	8.75
4.	Type IV	5.75 to 8.25
5.	Type II	5.75 to 6.75
6.	Type V (near Director's Bangalow)	6.75 to 8.75
7.	Academic Buildings	No pressure recorded
8.	Type I and Type IA	8 to 9.75
9.	Hostels 1,2,3,4, and 5	11, 8.75 to 10.25, 11, 10.5 and 9.5

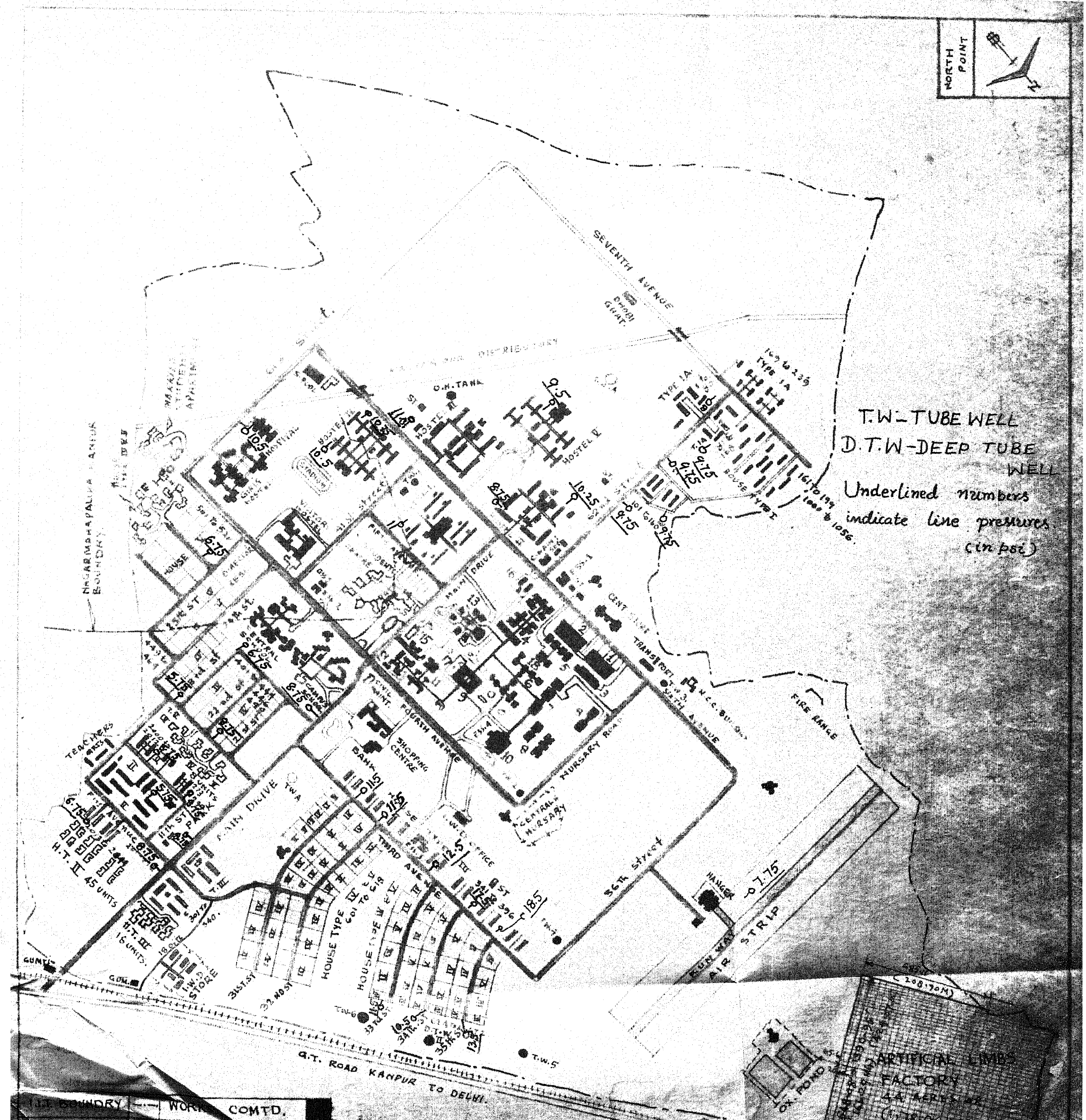


FIG. 24

PLAN OF I.I.T. CAMPUS

From the above figures it is quite clear that the worst affected areas are the type II quarters (upper floors) and the hostel buildings (second and third floor) where the residents are put to a lot of inconvenience. However, after connecting deep tube well No. 2 to the system there is some improvement in main line pressure.

In designing distribution systems faucet pressures of 5 psi are satisfactory for domestic needs. A minimum residual pressure of 50 ft. o (20 psi) of water is required for residential areas with three storeyed buildings. This important aspect should be considered while specifying the pressures to be maintained at the sources. For the deep tube wells the discharge is quite high and hence high head, high capacity pumps are desirable. Though a minimum fire pressure of 60 psi is recommended for residential areas, the same cannot be achieved under the present circumstances as it requires very high pressures to be maintained at the sources and hence the minimum pressure requirement for domestic use is to be taken as the criterion in design.

Elevated storage may be advantageously employed for pressure stabilization. The existing over head tank (70 ft. high from the bottom of the tank to the ground level) near hostel No. 3 can take care of only the

hostel area. It is desirable to have such tanks near the quarters having low pressure.

However, the economics of providing high capacity high head pumps or elevated tanks in conjunction with pumps should be worked out and the more economical method should be employed.

CHAPTER 6

CONCLUSIONS

The present investigations were mainly concerned with the basic understanding of the sources for the ground water supply for the I.I.T. Campus area. For this purpose, detailed studies of the aquifer characteristics and on the chemical quality of water were necessary.

With this object in view pumping tests were conducted on the shallow and deep aquifers of the campus and chemical analyses of water from them were also done. In light of the results of such investigations the current status was reviewed and the future needs projected. The studies conducted have led to the following conclusions:

1) There are three shallow aquifer systems up to a depth of 130 m, which were till recently the sources for water supply. These aquifers widely vary in their nature and extent, Frequent interfingering of these horizons with clay have reduced their capabilities as sources for water supply.

2) Out of the three systems, the aquifers in the third one with individual horizons reaching a thickness of 15 m as in tube well No. 3 are the most productive. These aquifers of the third system are present in the Northern part of the area (tube wells No. 3,4 and 5) and are responsible for the increase in discharges of the tube wells in this part as compared to tube well No. 1 in the Southern part of the campus.

3) The transmissibility coefficients as revealed by the pumping tests are 387500 lpd/meter (26065 gpd/ft) and 305250 lpd/meter (20500 gpd/ft.) for aquifers tapped by tube wells No. 3 and 5 respectively.

4) Although estimates made at the time of inception for all the six tube wells amounted to a total of 18,16,000 gpd (WILKE, 1966), at present only a total discharge of 8,36,000 gpd (37,62,000 lpd) at a drawdown of 18 to 20 ft. (5.4 to 6 m) is available from these shallow tube wells, which is about 46 per cent of the earlier estimate. This is due to the shut down of tube well No. 2 and nonavailability of water from tube well No. 6.

5) The chemical analyses of various constituents as determined for water from these shallow tube wells revealed the total dissolved solids content to be

201, 175, 202, 214 and 256 mg/l with chloride content of 10, 44, 45, 53 and 38 (tube wells No. 1,3,4,5 and 6) which are well within the standard specifications for drinking purposes.

6) Aquifers with considerable thickness and of coarse nature exist around the depths of 290 m to 400 m in general.

7) Their coefficients of transmissibility as revealed by the pumping tests on deep tube wells No. 1 and 2 are 447000 lpd/meter (30050 gpd/ft.) and 2346500 lpd/m (1,57,000 gpd/ft.) respectively. Thus the aquifers tapped by the deep tube well No. 1 are comparitively low in permeability.

8) It appears that there is a drastic variation at short distances of the quality of water from deep aquifers. For example, although deep tube well No. 1 yielded substantial quantity of water (21000 gpH), it is highly saline and the total dissolved solids content is well above the standard requirement (3750 mg/l) as against 1000 mg/l specified). However, deep tube well No. 2 is tapping similar sequence and its water is not saline, the T.D.S. content being 1230 mg/l which is slightly higher than the specified value.

9) A comparison of the chemical characteristics of water from shallow and deep aquifers has revealed a substantial variation between both.

10) The quality of water from deep aquifers can be improved by mixing it with that from shallow wells as evidenced from the results of chemical analysis of water samples taken from various consumer points of the campus after connecting the deep tube well No. 2 to the system.

11) The results of the step drawdown test are of value in judging the condition of wells as per WALTON'S recommendations. A detailed discussion on this is given in Chapter 4.

12) The proper location for future installation of shallow and deep tube wells is the Northern part of the Campus. In the Sourthern part not only the aquifers of the third system of shallow aquifers is missing, but the deep aquifers only provide saline water.

13) The projected demand for supply of water in the campus by the year 2001 stands at 1800000 gpd. However, even after connecting the deep tube well No. 2, the total available supply at any particular time stands at 13,96,000 gpd. This necessitates reinforcing the present supply with additional sources to cater completely to the projected demand by 2001. A detailed discussion on this aspect is provided in Chapter No. 5.

REFERENCES

1. Boulton, N.S. (1963): 'Analysis of Data from Non-equilibrium Pumping Tests Allowing for Delayed Yield from Storage', Proc. Inst. Civil Engineers, (London), Vol. 26, No. 6693.

2. Chaterji, G.C. (1969-70): 'The Status of Geohydrology in India', Water Resources Bulletin, Vol. 5-6, pp.3-18.

3. Chaturvedi, R.S. and Pathak, P.N. (1963): 'Flow of ground water towards pumping wells in the viscinity of a perennial stream', Univ. of Roorkee Research Journal, Vol. VI No. II pp. 97-122.

4. Chow, V.T. (1952): 'On the determination of transmissibility and storage coefficients from pumping test data', Am. Geophys. Union Trans. V. 33, No. 3, pp. 397-404.

5. Clark, F.W. (1924): 'The data of Geochemistry', U.S.G.S. Bull. 770, pp. 841.

6. DAVIS, G.H. (1966): 'Frequency distribution of dissolved solids in ground water', Ground Water, Vol. 4, No. 4, pp. 5-12.

7. Dewiest, R.J.M. (1966): 'Hydraulic model study of Nonsteady flow to Multiaquifer wells', Journal of Geophysical Research, Vol. 71, No. 4.

8. Gokhale, K.V.G.K. (1971): 'A case study for hydrogeological investigations in planning for ground water exploitation', Seventh Symposium, The Civil and Hydraulic Engineering Department, Water Resources, I.I.S.C. Bangalore, pp. B-11-1 to B-11-5.

9. Gupta, B.L. (1968): 'Hydrogeological studies in Muzzaffarnagar and parts of Meerut districts, U.P. (India), Ph.D. thesis (Unpublished), University of Roorkee, Roorkee.

10. Hem, J.D. (1959): 'Study and interpretation of Chemical characteristics of natural waters', U.S.G.S. Water Supply paper, 1473.

11. Hem, J.D. (1970): 'Study and interpretation of Chemical characteristics of natural waters', U.S.G.S. water supply paper 1473, 2nd Edition.

12. Hantush, M.S. (1956): 'Nonsteady flow to flowing wells in leaky aquifer', Journal of Geophysical research, Vol. 64, pp. 1043-1052.

13. Hantush, M.S. (1964): 'Drawdown around wells of variable discharge', Journal of Geophysical Research, Vol.69, no. 20, pp.4221-4285.

14. Herbert, R. (1968): 'Analysing pumping tests by Resistance Network analogue', Ground Water, Vol. 6, No. 2, pp. 12-18.

15. Jacob, C.E. (1944): 'Notes on determining permeability by pumping tests under water table conditions, U.S.G.S. mimeographed report.

16. Jacob, C.E. (1945): 'Adjustments for partial penetration of pumping well', U.S.G.S., Mimeographed report.

17. Jacob, C.E. (1946): 'Radial flow in a leaky Artesian aquifer', Transactions American Geophysical Union, Vol. 27, pp. 198-205.

18. Jacob, C.E. (1950): 'Flow of ground water', Engineering Hydraulics, H.Rouse (Ed.), Wilev, p.346.

19. Jaeger, J.C. (1959): 'The analysis of aquifer test data or thermal conductivity measurements which use a line source', Journal of Geophysical Research, V. 64, pp. 561-564.

20. Jone, P.H. and Hoffmann, W. (1967): 'Water Resources Investigation Programme for Upper Gangetic Plain', U.S. Department of Interior Geological Survey Report.

21. Karnjac, J. (1972): 'Reply to V. Thomas Sheahan's discussion and comments', Ground Water, Vol. 10, No.4, pp. 48-49.

22. Lennox, D.H. (1966): 'The analysis and applic tion of the step-drawdown test', Journal of Hydraulics Division, A.S.C.E., Vol. 92 HY6, Proc. Paper No. 496, pp.25-48.

23. Mehta, D. and Adyalkar (1962): 'Terai and Bhabar Zones of India along the Himalayan foot hills as potential ground water reservoirs', Economic Geology, Vol. 57, pp. 367-376.

24. Mithal, R.S. (1969): 'A reappraisal of ground water distribution and provinces in India', Proc. Symp. on ground water studies in Arid and semi-arid regions, Roorkee, pp. 495-526.

25. Mithal, R.S., Singhal, B.B.S. and Bajpai, I.P. (1973): 'Ground water conditions in the Gangetic Alluvium of Western Uttar Pradesh', International Symposium on development of ground water resources, Proc. Vol. 3, Madras, pp. V-53-V-61.

26. Mogg, T.L. (1969): 'Step-drawdown test needs critical review', Ground water, Vol. 7, No. 1, pp. 28-34.

27. Narasimhan, T.N. (1968): 'Ratio method for determining characteristics of ideal, leaky and bounded aquifers', Bull. Assoc. Sci. Hydrol. No.1

28. Nautiyal, S.P. (1955): 'Artesian Water Supply of Terai and Bhabar Zones of U.P.', Central Board of Geophysical Publ. No. 4, pp.49-66.

29. Pandey, M.P., Raghava Rao, K.V. and Karnath, K.R. (1961): 'Evaluation of ground water potentialities of the Bhabar formations of U.P.', Ind. Sci. Cong. 48th Session, pp. 212-213.

30. Papadopulos, I.S. (1966): 'Nonsteady flow to Multi-aquifer Wells', Journal of Geophysical Research, Vol.71, No. 20, pp. 4791.

31. Papadopulos, I.S. (1965): 'Nonsteady flow to a well in an infinite anisotropic aquifer', Symp. Intern. Assoc. Sci. Hydrology, Dubrovinik.

32. Piper, A.M. (1944): 'A graphic procedure in the geo-chemical interpretation of water analyses', Am. Geoph. Union Trans. V. 25, pp. 914-923.

33. Piper, A.M. (1953): 'A graphic procedure in geochemical interpretation of water analyses', U.S.G.S. Ground Water Note No. 12.

34. Piper, et.al. (1953): 'Native and contaminated ground waters in the long beach Santa Ana Area, California', U.S.G.S. Water Supply Paper 1136.

35. Pathak, B.D. (1954): 'Preliminary report on ground water conditions and the selection of sites for exploratory bore holes in U.P.', Geological Survey of India Memo No.16.

36. Pathak, B.D. (1955): 'The occurrence of ground water in the alluvial tracts of U.P. (India)', Central Board of Geoph. Publication No. 4, pp. 42-48.

37. Raghava Rao, K. (1965): 'Hydrogeological studies of alluvial areas in parts of Sharanpur district', Ph.D. Thesis (unpublished), University of Roorkee, Roorkee.

38. Rorabaugh (1953): 'Graphical and theoretical analysis of step drawdown test of artesian well', Proc. A.S.C.E., No. 362, Vol. 79.

39. Romero, J.C. (1970): 'The movement of bacteria and viruses through porous media', Ground Water, Vol. 8, No. 2, pp. 37-38.

40. Saleem, Z.A., (1970): 'Computer method for pumping test analysis', Ground water vol. 8, No. 5.

41. Sheahan, N.T. (1972): 'Discussion of well loss due to reduced formation permeability and comments on the step-drawdown test', Ground water, Vol. 10, No. 4, pp. 46-48.

42. Singhal, B.B.S. and Gupta, B.L. (1966):'Analysis of pumping test data from a well in the Indo-Gangetic alluvium of India and its bearing on the aquifer characteristics', Journal of Hydrology, Vol. 4, pp. 121-140.

43. Stallmann, R.W. (1962): 'Variable discharge without vertical leakages, in Ferris, J.G. et.al., 'Theory of aquifer tests', U.S.G.S. Water supply paper 1536-E, pp. 118-122.

44. Sternberg, Y.M. (1967): 'Transmissibility determination from Variable discharge pumping tests', Ground water Vol. 5, No. 4.

45. Stiff, H.A. Jr. (1951): 'The interpretation of chemical water analyses by means of patterns', Journal of petroleum technology, Tech. Note 84.

46. Taylor, Jr. G.C. (1959): 'Ground Water provinces of India', Economic Geology, Vol. 54, pp. 683-697.

47. Theis, C.V. (1935): 'The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groun water storage', Transactions American Geophysical Union, Vol. 16, pp. 519-524.

48. Verma, S. (1973): 'Hydrogeology of principal aquifers of Kanpur region', M.Tech. Thesis, IIT Kanpur.

49. Walton, W.C. (1962): 'Selected analytical methods for well and aquifer evaluation', Illinois State Water Surv. Bull. 49.

50. Walton, W.C. (1970): Ground Water Resource Evaluation, McGraw-Hill, New York.

51. Wenzel, L.K. (1942): 'Methods for determining permeability of water bearing materials with special reference to discharging well methods', U.S.G.S. Water Supply paper 887, pp. 192.

52. Wilke, H. (1966): Report on Sanitary Engineering Activities, Indian Institute of Technology, Kanpur, pp. 47-62.

LIST OF SYMBOLS

B - formation loss coefficient

b - thickness of aquifer

C - well loss coefficient

K - coefficient of permeability

Q - discharge

r - distance from observation well to pumping well

S - coefficient of storage

s - draw down

Δs - draw down change per log cycle of t.

s' residual draw down

$\Delta s'$ - residual draw-down change per log cycle of t/t'

t - time since pumping started

t' - time since pumping stopped

T - coefficient of transmissibility

$$u = \frac{r^2 S}{4T\,t}$$

$$W(u) = \text{well function} = \int_{\frac{r^2 S}{4T\,t}}^{\infty} \frac{e^{-x}}{x}\,dx$$

T.D.S. - total dissolved solids in mg/l

ΔQ_i, ΔQ_{i-1} - incremental discharge for the i^{th} step and $i-1^{th}$ step respectively.

Δs_i, Δs_{i-1} = incremental draw-down for the i^{th} step and $i-1^{th}$ step respectively